Federal Aviation Administration

DOT/FAA/AM-09/2
Office of Aerospace Medicine
Washington, DC 20591

The Outcome of ATC Message Length and Complexity on En Route Pilot Readback Performance

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January 2009

Final Report

OK-09-0434

Technical Report Documentation Page

1. Report No. DOT/FAA/AM-09/2	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle The outcome of ATC message length and complexity on en route pilot readback performance		5. Report Date January 2009 6. Performing Organization Code
7. Author(s) Prinzo OV,[1] Hendrix AM,[2] Hendrix R[2]		8. Performing Organization Report No.
9. Performing Organization Name and Address [1]FAA Civil Aerospace Medical Institute P.O. Box 25082 Oklahoma City, OK 73125	[2]Hendrix & Hendrix 15 Circle Drive Roswell, NM 88201	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency name and Address Office of Aerospace Medicine Federal Aviation Administration 800 Independence Ave., S.W. Washington, DC 20591		13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplemental Notes

This work was performed under Task AM-B-06-HRR-516.

16. Abstract

Field data and laboratory studies conducted in the 1990s reported the rate of pilot readback errors and communication problems increased as controller transmissions became more complex. This resulted in the recommendation that controllers send shorter messages to reduce the memory load imposed on pilots by complex messages. More than 10 yrs have passed since a comprehensive analysis quantified the types and frequency of readback errors and communication problems that occurred in the en route operational environment. Hence, a content analysis was performed on 51 hrs of pilot and controller messages that were transmitted from five en route facilities in the contiguous United States between March and August 2006. This report contains detailed and comprehensive descriptions of routine air traffic control (ATC) transmissions and how ATC message complexity and message length affected pilot readback performance. The results show that message complexity had a statistically significant effect on the production of errors of omission only, while message length affected both the production of errors of omission and readback errors (substitution and transposition errors). When pilots requested that controllers repeat their messages, often these messages included the names of fixes, waypoints, and intersections, as well as the name of the next controlling sector or facility. Five recommendations are made: (1) No more than three aviation topics should be included in an ATC transmission. (2) A route clearance should be given as a stand-alone transmission. (3) The names of all fix, waypoint, location, and other identifiers should be repeated, and if necessary, spelled out following their first recitation. For example, "CLEARED DIRECT COBAD THAT'S CHARLIE OSCAR BRAVO ALFA DELTA" or "CLEARED DIRECT COBAD C-O-B-A-D." (4) Slang should not be used or accepted as part of aviation phraseology. (5) Effort should be undertaken to reduce excessive words/phrases — on, your, to, is, etc.

17. Key Words Communications, ATC Communication, Air Traffic Control		18. Distribution Statement Document is available to the public through the Defense Technical Information Center, Ft. Belvior, VA 22060; and the National Technical Information Service, Springfield, VA 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 38	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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EXECUTIVE SUMMARY

This report describes and summarizes 51 hrs of air traffic control (ATC) communication that occurred during normal, day-to-day operations at five different en route centers between March and August 2006. On average, an aircraft requested and received air traffic services every 2 min 4 s, with approximately 10 messages exchanged from initial contact to the transfer of communications. The most frequently transmitted instructions involved changes in altitudes and switching pilots to another radio frequency.

Unlike the findings reported by Cardosi (1993) where 78% of the ATC messages involved one or two pieces of information (e.g., "contact center on one one two point three four" = 1 piece of information, while "contact [name] center on one one two point three four" = 2 pieces of information), we found that less than 1% of the controllers' messages had only one or two pieces of information (of the two examples, the first had a complexity value of 6, and the second had a complexity value of 7). In this report, 84% of the controllers' transmissions contained only one aviation topic (AT) (e.g., altitude, heading, speed), while messages with two ATs occurred in 14% of the other transmissions.

We also report a 10.2% increase in full readbacks and a 3.4% decrease in partial readbacks. Moreover, pilots who provided a full readback also included the complete call sign in approximately 64% of their responses. The fact that call signs were excluded in 10% of their readbacks and .2% of the spoken call signs were unintelligible leaves room for improvement. Unfortunately, both reports show the number of unacknowledged ATC transmissions at slightly more than 3%.

Approximately 71% of the pilot responses contained faulty readbacks — 67.4% contained one or more errors of omission that could be attributed to increases in the complexity of ATC messages. Changes in message complexity alone had no statistically significant effect on the production of readback errors (e.g., the substitution or transposition of numbers in the controller's original transmissions).

Readback errors comprised the remaining 4.0% of the pilots' faulty readbacks — 78% resulted from a combination of an error of omission plus one or more substitutions (89%) or transpositions (11%). Unlike message complexity, message length affected both the production of errors of omission and readback errors. There were more errors of omission as ATC message length increased from short (1 AT), to moderate (2ATs), and long (3 or more ATs). Redundant information might be eliminated to increase the economy of capacity limitations of verbal working memory.

Readback errors increased once ATC messages included two or more ATs. The most common readback errors involved altitude and altitude restrictions, followed by changes in radio frequency, route/position clearances, and altimeter settings. Some of the readback errors involved slang. That is, an ATC instruction to "contact center on one one niner point zero," was occasionally read back as "nineteen zip" or "nineteen nothing." What is worrisome for aviation safety is that other pilots may not understand these types of readbacks (especially pilots who are less proficient in aviation English or making their first flights into the U.S.).

A common practice among pilots is to acknowledge controller instructions/advisories with either their call sign only or their call sign plus roger/wilco. Also common is a response such as "DOWN TO TWO FIVE ZERO" (when acknowledging an instruction to reduce speed or assignment of a new altitude) and partial readback (responding to only one of two or more instructions). These examples illustrate pilot readbacks that might leave the controller in doubt of pilot understanding and may thus adversely affect safety.

Possibly to avoid the risk of either reading back the contents of an ATC transmission meant for another aircraft (stolen transmission) or reading back its contents incorrectly, pilots asked the controller for either a full or partial repeat of the original message. Of these 112 pilot requests, five involved a call sign misspoken by the controller to which the pilot wanted confirmation of the message's recipient. A closer look at requests showed that 67.5% had either a fix/intersection or facility name included as part of their content — and many of these messages involved route clearances and the transfer of communications. The names of location identifiers, fixes, intersections, navigational aides, etc. are critical to navigation; thus, pilots were prudent in requesting either the repetition or confirmation of previously heard identifiers.

Based on our findings, we recommend that:

1) No more than three ATs should be included in an ATC transmission. 2) Route clearances should be given separately as stand-alone transmissions. 3) The names of all fixes, waypoints, locations, and other identifiers should be repeated, and if necessary, spelled out following their first recitation. For example, "CLEARED DIRECT COBAD – CHARLIE-OSCAR-BRAVO-ALFA-DELTA," or "CLEARED DIRECT COBAD – C-O-B-A-D COBAD." 4) Slang should not be accepted by ATC as part of a pilot readback.

The Outcome of ATC Message Length and Complexity on En Route Pilot Readback Performance

Many attempts to communicate are nullified by saying too much.

— Robert Greenleaf
Founder, Modern Servant Leadership Movement

More than 10 years have lapsed since a comprehensive analysis was undertaken to quantify and report the types and frequencies of pilot readback errors and air traffic control (ATC) communication problems that occur in the operational environment. In particular, it is important to determine whether the findings from the previous decade (Cardosi, 1993; Cardosi, Brett, & Han 1996; Prinzo, 1996; Prinzo & Britton 1993) remain representative of routine communications in 2006.

This is the second of two reports that investigated the role of ATC message complexity and message length on operational communications between controllers and pilots. In the first report, Prinzo, Hendrix, and Hendrix (2006) describe and summarize the controller-pilot communication process that takes place during normal, day-to-day operations in the terminal radar approach control (TRACON) environment. In this report, we apply the same theoretical approach and methodology to the analysis of operational communications in the en route environment using digital audio tapes (DATs) provided by five Air Route Traffic Control Centers (ARTCCs).

In their 2006 report, Prinzo and colleagues took the concept of message complexity that was originally proposed by Cardosi (1993) for the ARTCC domain, modified by Cardosi et al. (1996) for the TRACON domain, further refined it and provided a theory-driven rationale for computing message complexity. In particular, Wasow (1997) suggested that an utterance's complexity can be derived from the amount of information expressed in its constituents as measured by the number of words, syntactic nodes, or phrasal nodes in the constituent. They further cite the seminal work of Miller (1956) and Baddeley (1987, 2000) and Baddeley and colleagues (1974, 1975), who provide a strong theoretical basis for capacity and processing components of verbal working memory. Miller proposed that verbal working memory is limited in the amount of information that can be actively processed ($7^{\pm 2}$), while Baddeley added a temporal constraint — external information encoded as mental representations must be actively rehearsed; otherwise, they begin to decay in about 2 s or are overwritten by incoming information.

Prinzo et al. (2006) attempted to remove as much of the subjective component as possible when counting the complexity present in communication elements. As noted in Prinzo (1996), communication elements are the fundamental unit of meaningful verbal language. In aviation, communication elements are identified according to their functionality (Address/Addressee, Courtesy, Instruction/Clearance, Advisory/Remark, Request, and Non-Codable) and are restricted with regard to their aviation topic (AT: altitude, heading, speed, traffic, route, etc.: Prinzo, Britton, & Hendrix 1995).

For Prinzo et al. (2006), the complexity value of a communication element is defined by each word or set of words transmitted by ATC to the flight deck that contains a new piece of information critical to the understanding of that communication element. Identifying the amount of information in ATC utterances begins by parsing a message into its communication elements, then defining each communication element according to its speech act and AT, assigning a complexity value to each communication element, and finally, summing the complexity values to arrive at the level of complexity for each message. They developed several user guides for determining the message complexity for the TRACON (Prinzo et al., 2006) and En Route (see Appendices) environments.

Their scoring scheme assumes that communication elements that contain more information should be assigned larger values. This assumption holds, particularly for altitude instructions. For example, the numerical values present in altitude instructions such as "three thousand five hundred," "one-zero thousand," and "four thousand" are likely to impose *quantitatively* different loads on working memory. In particular, it takes longer to pronounce 'three thousand five hundred' than 'four thousand' (e.g., articulatory loop proposed by Baddeley, 2000) and utilizes more capacity because it contains more words (Miller, 1956). In fact, Morrow and Prinzo (1999) found that when serial reproduction is required, numerical content that utilizes more resources may be partially or completely omitted or lead the pilot to request a repetition.

In this report, we describe and summarize the controller-pilot communication process that takes place

during normal, day-to-day operations in the en route environment. We also apply the same theoretical approach and methodology that was developed for the TRACON environment to the analysis of operational communications in the en route environment (see Prinzo et al., 2006). Like the TRACON report, the purpose of this report is to (1) provide current information regarding routine en route communication practices, (2) document the types of transmissions that are exchanged between pilots and the certified professional controllers who provide them with en route ATC services, and (3) record communication problems by type and frequency of occurrence. Like the TRACON report, we restricted the analysis of ATC messages to instructions/clearances, altimeter settings, (or both), and the pilots' responses to these messages.

This report is similar to Cardosi's (1993), in that (1) each report examined voice tape samples from Chicago, Los Angeles, New York, and Oakland ARTCCs; (2) the sampled ARTCCs had a relatively high proportion of foreign carriers; and (3) the communication samples included both high- and low-altitude sectors.

It differs from the Cardosi report in the following ways: (1) Cardosi measured message complexity "as the number of separate elements contained in a single transmission. Each word, or set of words, the controller said that contained a new piece of information to the pilot and was critical to the understanding of the message was considered to be an element." [p3]. For example, "… contact Minneapolis Center 118.8" was considered one piece of information if the pilot was already on a Minneapolis Center frequency and as two pieces of information if the pilot received it while communicating with a different ARTCC. We, on the other hand, treated "... Contact Minneapolis Center 118.8" as one communication element with a complexity value = 6. Our rationale was that each digit comprising the radio frequency imposes a memory load that could result in the pilot erroneously reading back the wrong facility/function; omitting, transposing, or substituting any (or all) of the digits in the radio frequency; or both. Figure 1 shows how we evaluated communication elements and assigned complexity values. Each anchor word is also assigned a value = 1; in this case, they are the words "contact" and "point." (2) Cardosi evaluated voice tapes from eight different ARTCCs during high and moderate traffic situations, and we examined voice tapes representative of high traffic situations from five different ARTCCs. (3) Cardosi examined 48 hrs of voice tapes, and we examined 51 hrs of voice tapes.

This report is also similar to the Cardosi (1993) and Prinzo et al. (2006) reports in that they provided descriptions and descriptive statistics related to three general types of information: Routine ATC Communications, Pilot Faulty Readback Performance, and Pilot Requests for Repeat of an ATC Transmission. Like Cardosi (1993) and Prinzo et al. (2006), complexity values were determined for the transmissions that contained a) instruction/clearance speech acts that involved heading, heading modifier, altitude, altitude restriction, speed, approach/departure, frequency, holding, route/position, and transponder ATs, and b) advisory speech acts that involved the altimeter AT.

In this report, separate analyses were performed for routine ATC communications and pilot requests for repeat. Routine ATC Communications are related to (1) types of information included in ATC messages, (2) ATC message length and complexity, (3) pilot responses to ATC messages, and (4) pilot use of call signs in readbacks. The analysis of Pilot Faulty Readback Performance involves (1) pilot errors of omission, (2) pilot readback errors, (3) message complexity and pilot readback performance, and (4) message length and pilot readback performance. The analysis of Pilot Requests for Repeat of an ATC transmission were further subdivided into four types of requests: (1) requests for the repeat of a specific aviation topic, (2) requests for the repeat of an entire transmission, (3) requests for confirmation/verification of a specific aviation topic, and (4) requests for confirmation that the transmission was for them.

Complexity Value for Transfer of Communication:					
ANCHORs and (Variables):	CONTACT	(facility/function)	(frequency	+ POINT	+ digits)
Complexity:	1	1	2	+ 1	+ 1(1)
Example:	"contact	Minneapolis Center	one one eight	point	eight"
	1	1	2	1	1

Figure 1. Assigning a Complexity Value to an Aviation Topic.

METHOD

Materials

Audiotapes. Each en route facility was asked to provide 10 hrs of voice communications representing heavy concentrations of international arrivals, departures, or both. The tapes were of communications recorded between March and August 2006. The facility representative made copies of their Digital Audio Tape (DAT) recordings using the NiceLogger™ Digital Voice Recorder System. DATs contained separate voice records of all communication transmitted on the radio frequency assigned to a particular sector position on the left channel. The NiceLogger™ Digital Voice Reproducer System decoded and displayed time and correlated it with the voice stream in real time.

Guides to the Computation of En Route Message Complexity. To compute ATC message complexity, the *Guide to the Computation of Complexity*: *ATC Instruction/Clearance Aviation Topics* and the *Guide to the Computation of Complexity*: *ATC Advisory Aviation Topics* were developed and applied to each aviation topic in controller transmissions. These guides appear in Appendix A and Appendix B, respectively. Table 1 shows an example of the complexity value assigned to the phraseology used to deliver an altitude instruction. The first column presents the AT, the second column presents the complexity value, and the third column presents the phraseology extracted from *FAA Order 7110.65P* (2004) to support the delivery of that service. In several cases, the phraseology used by the speaker did not appear in *FAA Order 7110.65* (e.g., good rate) but was used so frequently that they were assigned values. Capitalized words designate anchors and italicized words identify qualifiers that vary according to the geographical location and aircraft position.

To determine complexity value, anchors, qualifiers, and excessive verbiage are assigned a value indicative of new information or importance towards the understanding of an instruction or advisory. In most cases each anchor is counted as one element of complexity. There are several exceptions, however. Some communication elements contain multiple anchors, as in the case "TURN LEFT/RIGHT HEADING (degrees)." The anchor "TURN LEFT/RIGHT" provides the direction of the turn while "HEADING" indicates the aircraft's bearing. Also, numerical qualifiers must be evaluated according to the phraseology used by the speaker. That is, the number 'three thousand five hundred' was

Table 1. Excerpt from the *Guide to the Computation of Complexity.*

AVIATION TOPIC	COMPLEXITY	PHRASEOLOGY
Altitude		4=FLIGHT LEVEL + *(altitude) three digits* 3=*(altitude) two digits* +THOUSAND 2=*(altitude) one digit* + THOUSAND 3=*(altitude) two digits* + HUNDRED 2=*(altitude) one digit* + HUNDRED 2=*(altitude) two digits* 1=*(altitude) one digit*
	6	DESCEND/CLIMB & MAINTAIN *(altitude)* THOUSAND *(altitude)* HUNDRED *three* *five*
	6	DESCEND/CLIMB & MAINTAIN *(altitude)* THOUSAND *(altitude)* THOUSAND *one two* *twelve*
	6	DESCEND/CLIMB & MAINTAIN FLIGHT LEVEL *(altitude)* *two three zero*
	5	DESCEND/CLIMB & MAINTAIN *(altitude)* THOUSAND *one zero*
	4	DESCEND/CLIMB & MAINTAIN *(altitude)* THOUSAND *four*
	*4-8	CONTINUE CLIMB/DESCENT TO *(altitude)*
	*4-8	AMEND YOUR ALTITUDE DESCEND/CLIMB MAINTAIN *(altitude)*
	*3-7	AMEND YOUR ALTITUDE MAINTAIN *(altitude)*
	*3-6	DESCEND/CLIMB TO *(altitude)*
	*2-5	MAINTAIN *(altitude)*
	*1-3	(*altitude,* omitted "THOUSAND" "HUNDRED" "FLIGHT LEVEL")

***** The complexity value varies as a function of the altitude

assigned a value of 4 (a value of one for each number and a value of one for the anchor 'hundred'), since it would be more demanding than either one-zero thousand (value = 3) or four thousand (value = 2). Finally, one element of complexity should be added for excessive verbiage. Excessive verbiage is determined by comparing the speaker's utterance against the phraseology designated in *FAA Order 7110.65*. The coding procedures used to evaluate the controllers' transmissions were applied to pilot readbacks. The level of complexity of an ATC message is the sum of the values across each aviation topic in the transmission. Thus, complexity value (CV) is to aviation topic as level of complexity (CL) is to an ATC message.

Guides to the Classification of Pilot Readback Errors. As used here, a readback error is defined as an unsuccessful attempt by a pilot to correctly read back the information contained in the communication elements that comprise the original message transmitted by ATC. To aid in the classification of readback errors, the *Guide to the Computation of Pilot Readback Errors*: *Instruction/Clearance Aviation Topics* and the *Guide to the Computation of Pilot Readback Errors*: *Advisory Aviation Topics* were developed and applied to each pilot readback. They are presented in Appendix C and Appendix D, respectively.

Many of the readback error types are common to all ATs. The more typical ones include substitution, transposition, and omission errors. Presented in Table 2 is an example of nine possible readback errors for an instruction to change altitude. The column to the right displays the various types of altitude readback errors. Preceding each example of a particular type of readback error is the original ATC message. For example, ATC might transmit the following message to AAL10, "AMERICAN TEN TURN LEFT HEADING TWO ONE ZERO." If the pilot read back either "THREE ONE ZERO" or "SIX ZERO," it is coded as a substitution error since the numbers in the original heading instruction include neither a three nor a six.

Some types of readback errors may pose a greater risk to safety than others. For example, transposing a number in an aviation topic may be more of a threat in some situations than the omission of a number or the substitution of an anchor word with its synonym. To ensure safety, controllers listen to pilot readbacks while monitoring aircraft along their route of flight and will intervene when necessary. In fact, Prinzo et al. (2006) suggest that correcting a faulty readback might be a conservative component of the hearback process. As such, it may be reserved for readbacks with potentially adverse consequences to safety, aircraft performance, or traffic flow.

Subject Matter Experts (SMEs)

The first author has 14 yrs of experience analyzing pilot controller communications. The second author was an instrument-rated pilot and former controller who had worked as an FAA Academy instructor for 8 yrs and had worked for 12 yrs in FAA supervision and management. The third author has assisted the second author in encoding pilot-controller communications for more than 11 yrs.

Procedure

Data Transcription. One set of audiocassette tapes was dubbed from each DAT and provided to the transcribers who used them to generate the verbatim transcripts. Each message was preceded by its onset and offset time as it

Table 2. Excerpt from the *Guide to the Computation of Pilot Readback Errors.*

Classification of Readback Errors	Examples
Readback Errors Type (ALT)	
ATC: "American Ten climb and maintain one two thousand"	
1 = Substitution of message numbers/flight level vs. thousand	1-"maintain one **three** thousand" "maintain **flight level** one two"
2 = Substitution of climb with descend or descend with climb	2-"**descend** maintain one two thousand"
3 = Substitution of message numbers with incorrect climb/descend	3-"**descend** maintain **one three** thousand"
4 = Transposition of message numbers with incorrect climb/descend	4-"**descend** maintain **two one** thousand"
5 = Transposition of message numbers	5-"climb maintain **two one** thousand"
6 = One type of information read back as another type of information	6-"AAL Ten one two zero **knots**"
7 = Omission of anchor word(s)	7-"one two"
8 = Omission of number elements	8-"climb maintain"
9 = Omission of anchor word(s) and some number elements	9-"climb two thousand"

was typed onto an electronic copy of the Aviation Topics Speech Acts Taxonomy-Coding Form (ATSAT-CF; Prinzo, Britton, & Hendrix, 1995). Once the transcribers finished a set of tapes for an ARTCC, the second and third authors received copies of the transcripts, video maps, air carrier identifiers, and routes for use during the encoding process.

Message Encoding Process. Message encoding was a four-stage process. Some of the stages had multiple parts. Each stage is described.

Step 1: Parsing and Labeling Communication Elements. In Step 1, each controller message was parsed into communication elements and categorized by speech act and aviation topic using the protocol established by Prinzo, et al. (2006). In Table 3 under the column labeled "T1" is the receiver identification, under "T2" is the speaker identification, "T3" contains a speed instruction (IS), and "T4" shows that the last communication element is an instruction to change altitude (IA). There are four communication elements: two instructions and the speaker (SID) and receiver (RID) of the transmission.

Step 2: Computing Complexity. In Step 2, the *Guide to the Computation of Complexity* was used to look up the appropriate complexity value according to the phraseology used by the controller for Instruction/Clearance ATs (see Appendix A) and for Advisory ATs (see Appendix B). Complexity values were assigned to all instruction and advisory ATs. As seen in Table 4, neither SID nor RID were evaluated for complexity, so a value of "0" was entered in each of those columns. For the first example, the complexity value of IS = 2 and IA = 6. The message's complexity level (CL) is the sum of the complexity values. For that example, CL = 8. In the second example, there is a speed (IS), altitude (IA), and altimeter (AW) issued by ATC. The complexity values are IS = 5, IA = 5, and AW = 4. The transmission has a CL = 14.

Step 3: Identifying Message Couplets. In Step 3, each ATC transmission was paired with the pilot's reply to that message. The aircraft identifier and message contents were used to match the controller's transmission with the pilot's response. As shown in Table 5, the controller transmitted a message to the flight deck (FD) of Ownship 6410, to which the pilot replied with a general acknowledgement, the readback of the speed and altitude instructions, followed by the aircraft's call sign.

Step 4: Identifying Readback Performance. In Step 4, each readback was evaluated for accuracy. This is a multistage encoding process. As shown in Table 6, if no problem was present then a '0' was entered under the column labeled "Com Prob"; otherwise, the number of communication problems was recorded for the entire

Table 3. ATC Messages Parsed and Categorized by Speech Acts and Aviation Topics.

SPKR	Message	T1	T2	T3	T4
ATC	OWNSHIP SIXTY FOUR TEN / [FID] / RESUME NORMAL SPEED / CLIMB MAINTAIN *FLIGHT LEVEL TWO THREE ZERO*	RID	SID	IS	IA

Table 4. Complexity Values Assigned to Instruction and Advisory Aviation Topics.

SPKR	Message	RID	SID	IS	IA	AW	CL
ATC	OWNSHIP SIXTY FOUR TEN / [FID] / RESUME NORMAL SPEED / CLIMB MAINTAIN *FLIGHT LEVEL TWO THREE ZERO*	0	0	2	6	0	8
ATC	OWNSHIP FOUR THREE SIX / [FID] / MAINTAIN TWO FIVE ZERO KNOTS / DESCEND AND MAINTAIN ONE FOUR THOUSAND / [LOCATION] ALTIMETER IS TWO NINER THREE EIGHT	0	0	5	5	4	14

Table 5. ATC Message Couplets.

SPKR	Message	T1	T2	T3	T4
ATC	OWNSHIP SIXTY FOUR TEN / [FID] / RESUME NORMAL SPEED / CLIMB MAINTAIN *FLIGHT LEVEL TWO THREE ZERO*	RID	SID	IS	IA
FD6410	OKAY / NORMAL SPEED /AND UP TO *FLIGHT LEVEL TWO FOUR ZERO* /OWNSHIP SIXTY FOUR TEN	IGA	IS	IA	SID

Table 6. Identification of Communication Problems.

SPKR	Message	Com Prob	Type Prob	Type RBE	Type AT
ATC	OWNSHIP SIXTY FOUR TEN/ [FID] / RESUME NORMAL SPEED / CLIMB MAINTAIN *FLIGHT LEVEL* ***TWO THREE ZERO***	1	1	1	IA
FD6410	OKAY / NORMAL SPEED /AND UP TO *FLIGHT LEVEL* ***TWO FOUR ZERO*** /OWNSHIP SIXTY FOUR TEN	1	1	1	IA

message. There was one identified communication problem in the couplet, so the value of "1" appears in that column.

Then the type of communication problem was coded under the column labeled "Type Prob." The types of communication problems were coded as readback error (RBE) = 1, request for repeat (RfR) = 2, or their combination = 3. If a communication problem had been identified that did not match the pre-defined classifications, then it would have been assigned a new value and included in the classification scheme.

If faulty readback performance involved instructions/clearances then the *Guide to the Classification of Pilot Readback Errors: Instruction/Clearance Aviation Topics* was used (see Appendix C); if it involved an advisory then we referred to *Pilot Readback Errors: Advisory Aviation Topics* (see Appendix D). As shown in Table 6, there is an error involving the readback of the altitude instruction. Using the *Guide to the Classification of Pilot Readback Errors: Instruction/Clearance Aviation Topics* (Appendix C), the readback error was assigned a particular value that depended upon its specific type of error. There were three general classes of readback errors — substitution, transposition, and omission — and each one had a particular value that depended upon the nature of the readback error.

In the example, the controller instructed the pilot to "CLIMB MAINTAIN FLIGHT LEVEL TWO THREE ZERO" and the pilot erroneously read back "FLIGHT LEVEL TWO FOUR ZERO." The readback error was classified as a substitution error since none of the numbers in the original altitude instruction contained the number four, and it was assigned the value = 1.

The last part of the identification of readback errors defined which of the ATs were read back incorrectly. Since the faulty readback involved the altitude instruction, "IA" was coded under the column labeled "Type AT."

Encoding Reliability. Inter-rater reliability was evaluated by having the first and second author randomly encode the same randomly selected set of 125 messages (25 for each facility). Since the first and second author both used the guides presented in Appendices A and B to compute complexity, it was expected that there would be a high percentage of agreement between them. Krippendorff's alpha (α),[1] a reliability coefficient, was performed on their ratings as each set of data was completed and after all the data were encoded. Treating the ratings as ordinal data produced $\alpha = .945$, indicating high inter-coder agreement.

Sector Descriptions

Chicago ARTCC. The transcriptions are of pilot/controller communication from two en route sectors. They are low-altitude arrival and departure sectors, surface to flight level two three zero joining a terminal facility. The arrival sector received traffic from other en route sectors and descended the aircraft to 8,000 feet via vectors and arrival routes and transferred control to the approach control. The departure sector received aircraft from the approach control and climbed them to higher altitudes and transferred control to other en route sectors. There were a few arrival aircraft to outlying airports in the departure sector requiring descent and transfer of control to an approach facility or other en route sectors.

Los Angeles ARTCC. The transcripts are of 10 en route sectors. The sectors are north, east, and south of the greater Los Angeles area. In the low-altitude sectors (below flight level two four zero) the traffic is climbing/descending to/from approach areas to en route altitudes or high altitude. In the high-altitude sectors (flight level two four zero and above) the traffic is also climbing and descending, but to and from low-altitude sectors plus en route traffic.

Miami ARTCC. The transcripts are of pilot controller communications of arrival and departure sectors. The airspace is the outer peripheral of the Florida peninsula. The airports are Fort Myers, Key West, Marathon, Miami, and Palm Beach. One sector transcription includes coordination and communication change with Havana

[1] Krippendorff's alpha is a reliability coefficient that was originally developed for evaluating agreement between coders performing a content analysis. It is a statistic that is widely applicable wherever two or more methods of processing data are applied to the same set of objects, units of analysis, or items (Krippendorff, 1980). Hayes (2005) developed an SPSS procedure to compute Krippendorff's alpha that is available on the Internet.

Center. The traffic is climbing and descending; there is some VFR traffic and a few military aircraft flying en route to warning areas.

New York ARTCC. The transcripts are of pilot/controller communications from offshore sectors. The area is just east of the northeast coast of the U.S. The flow of traffic is inbound to Boston/New York terminal areas, with a few overflights to Canada. The outbound traffic is to Europe and the Caribbean Islands, plus a refueling track.

Oakland ARTCC. The transcripts are of pilot/controller communications in sectors to the west of the Continental United States. The traffic is mostly high altitude and climbing and descending. The sectors are setting up the outbound traffic for their oceanic routes/altitudes and receiving traffic to the U.S. from the Orient and Northwest U.S. The outbound traffic is handed-off to an Ocean sector with a communication transfer to ARINC, en route frequencies, or CPDLC, while the inbounds are handed off and communication transferred to another Oakland sector. The traffic is mostly domestic air carriers and several foreign air carriers. There also are several military aircraft working a refueling area.

RESULTS

Routine ATC Communication

In this report, 51 hr 3 min 20 s of communications were analyzed. The amount of voice communications varied from 58 min 55 s on one communication sample to 5 hr 13 min 49 s on another. Approximately 89% of the communications occurred between 6:00 a.m. and 6:00 p.m. The data are representative of 77 controllers who worked arrival, departure, and mixed traffic flows at five different ARTCCs within the contiguous U.S. between March and August 2006.

Presented in Table 7 is the number of transmissions, number of U.S. and Foreign Registry aircraft, and duration of the communication samples for each ARTCC facility. The grand total presented under the heading "Number of Aircraft" and "Duration of Communication Samples" revealed that, on average, one aircraft requested and received air traffic services every 2 min 4 s. The number of ground-to-air transmissions averaged 4.62 messages per aircraft (Number of ATC Transmissions/Number of Aircraft). From initial contact to the hand-off to the next controller in sequence, the entire transactional communication set involved the exchange of 10 messages between a controller and pilot (this includes all of the pilot transmissions to the controller) and an allocation of 28.24 s of airtime (per aircraft).

Types of Information Included in ATC Messages. Like the Cardosi 1993 report, the computation of message complexity was restricted to include only controllers' messages that transmitted a combination of instructions, clearances, and advisories (i.e., radar contact with altimetry or radar services terminated with a frequency change). Of the 6,875 controller-to-pilot transmissions, 4,261 met the selection criteria and underwent further analysis.

Figure 2 shows that of the 5,158 ATs transmitted to pilots, the ones most frequently transmitted included altitudes, radio frequency assignments, and route/position clearances. There were 11 instances where pilots were instructed to hold at a particular location (e.g., "OWNSHIP ONE EIGHTY THREE ROGER IS CLEARED TO PIVOT HOLD NORTHEAST AS PUBLISHED EXCEPT ONE ZERO MILE LEGS APPROVED TEN MILE EXPECT FURTHER CLEARANCE TWO TWO ZERO FIVE.").

ATC Message Length and Complexity. Table 8 shows that about 92% of the ATC transmissions had only instructions/clearances, 2% contained only an altimetry advisory, and nearly 6% combined instructions/clearances with the

Table 7. Number of Transmissions, Number of Aircraft, and Communication Durations Presented by ARTCC Facility.

Source	Number of Transmissions					Number of Aircraft		Duration of Communication Samples
	ATC	Flight Deck	Land-line	Unsure	Total	US	Foreign	
Chicago	1233	1326	251	2	2812	214	42	9 h 29 min 35 s
Los Angeles	1837	1998	282	5	4122	442	57	11 h 08 min 59 s
Miami	1999	2150	222	1	4372	370	32	9 h 39 min 01s
New York	1028	1035	195	2	2260	125	41	10 h 37 min 39 s
Oakland	778	865	177	1	1821	91	65	10 h 08 min 06 s
Grand Total	6875	7374	1127	11	15387	1252	235	51 h 03 min 20 s

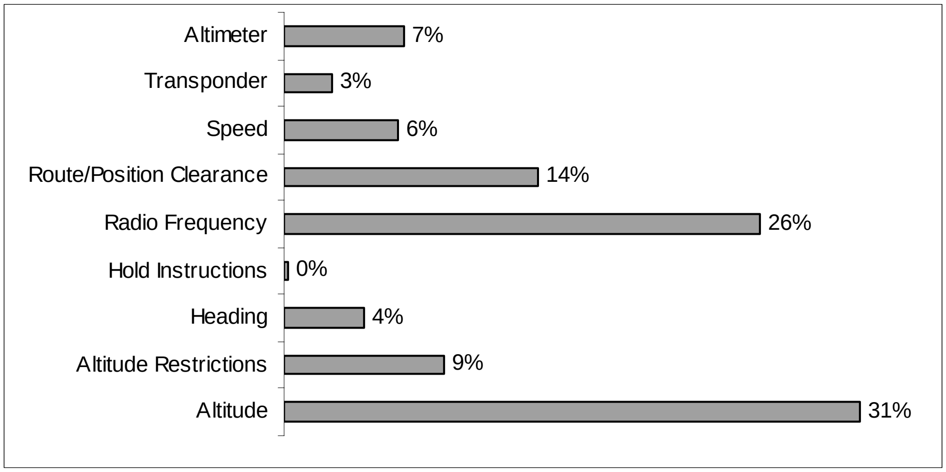

Figure 2. Percentages of ATC Instruction/Clearance Aviation Topics.

Table 8. Frequency Distribution of the Types of Speech Acts Presented by Message Length.

Message Length	Types of Speech Acts			Total Percentage
	Clearances and Instructions	Altimeter Advisory	Combination	
1	82.2%	2.1%		84.3%
2	9.0%		5.1%	14.1%
3	.8%		.6%	1.4%
4	.1%			.1%
Total Percentages	92.1%	2.1%	5.8%	100.0%

altimetry advisory. Furthermore, 84% of the transmissions had one speech act; rarely did controllers include three or more speech acts in their transmissions.

An Analysis of Variance (ANOVA) was conducted on the mean number of speech acts in ATC transmissions according to facility and traffic flow. The results indicated that messages were longer when traffic was in an arrival as compared with either a departure or mixed flow [$F(2,64)=4.98$, $p=.01$]. However, the statistically significant ARTCC Facility by Traffic Flow interaction [$F(6,64)=2.39$, $p=.038$], displayed in Figure 3, shows the main effect of traffic flow is restricted to the controllers at the Chicago and Los Angeles ARTCCs who sent longer transmissions only when traffic was on an arrival flow;[2] otherwise, message length was comparable across ARTCC facilities and traffic flows.

Table 9 shows the distribution of ATC messages according to their complexity level (CL) and message length (ML). An examination of the row totals (see column "CL Percentages") reveals that, unlike the findings reported by Cardosi (1993), where 78% of the ATC messages had one (e.g., frequency change) or two pieces of information (e.g., turn left heading 090), less than 1% of the transmissions analyzed in this report did (.40% had a CL = 1 [e.g., normal speed, ident], and another 9% had a CL = 2 [e.g., start your decent now]).

Table 9 reveals that 51% of the ATC transmissions with a ML = 1 had a CL = 6-7. For example a route clearance such as "CLEARED DIRECT CAMRN" (CL = 2) is less complex than "CROSS HECTOR AT AND MANINTAIN FLIGHT LEVEL TWO FOUR ZERO TWENTY FOUR," (CL = 8), which is less complex than "CLEARED TO HOUSTON AFTER DOVEY DIRECT NANTUCKET DIRECT BOSTON DIRECT CHARLIE MIKE KILO JET SEVEN FIVE TO GOLF VICTOR ECHO JECT THREE SEVEN TO SIERRA JULIETT INDIA DIRECT HOTEL ROMEO VICTOR DIRECT LIMA LIMA ALFA DIRECT VICTOR UNIFORM HOTEL DIRECT PAPA SIERRA XRAY AND THE GLAND THREE ARRIVAL TO HOUSTON"(CL = 24).

The most complex ATC message had a CL = 31 and it contained three speech acts (route clearance, altitude, and speed instructions): "CLEARED TO DELTA GOLF ALFA ALFA AIRPORT AFTER CHAMP DIRECT CREEQ DIRECT KWLTY THREE FIVE THREE ZERO NORTH SIX ZERO WEST THREE THREE FIVE ZERO NORTH FIVE FIVE WEST THREE ONE FIVE ZERO NORTH FIVE ZERO WEST TWO NINER FIVE ZERO NORTH FOUR FIVE WEST TWO SEVEN TWO ZERO NORTH FOUR ZERO WEST TWO FOUR THREE ZERO NORTH THREE

[2] Post hoc comparisons were performed using the Tukey statistic.

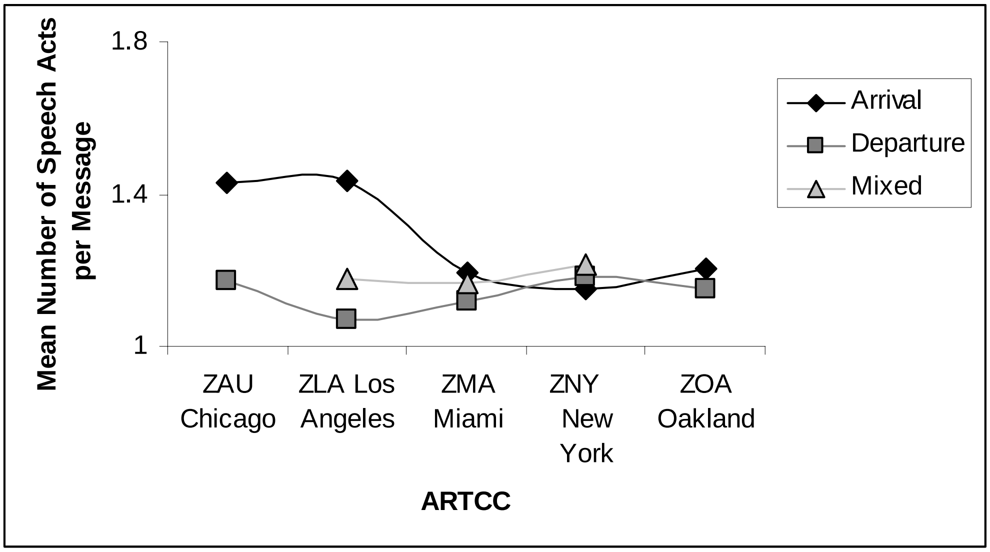

Figure 3. ATC Message Length Presented by ARTCC Facility and Traffic Flow.

Table 9. ATC Messages Presented by Level of Complexity and Message Length**.**

	Message Length				
Complexity Level	**1**	**2**	**3**	**4**	**CL Percentages**
1	.40%				0.40%
2	9.00%				9.00%
3	5.72%				5.72%
4	7.80%	.31%			8.11%
5	9.13%	.19%			9.32%
6	28.67%	.74%			29.41%
7	20.54%	1.04%			21.58%
8	2.94%	3.75%	.02%		6.71%
9	.02%	4.00%	.26%		4.28%
10	.02%	1.45%	.17%		1.64%
11	.05%	2.04%	.24%		2.33%
12		.33%	.12%	.02%	.47%
13		.21%	.10%		.31%
14 or more[1]		.10%	.52%	.10%	.72%
ML Percentages	84.32%	14.15%	1.42%	.12%	100.00%

[1] CL ranged from 1 – 31. There were only 3 transmissions with 4 communication elements and a CL ≥ 12.

FIVE WEST ELTIN GAMBA MAINTAIN FLIGHT LEVEL THREE TWO ZERO FOR NOW MAINTAIN MACH POINT EIGHT FIVE."

Pilot Responses to ATC Messages. In response to the 4,261 ATC messages, there were 3,437 full readbacks, 363 partial readbacks, 126 acknowledgment only (e.g., "Roger," "Wilco"), 26 courtesies such as "Thank you," 160 messages with no acknowledgment, and 17 transmissions were retransmitted by ATC because they were previously blocked. In addition to these messages, there were 152 other replies, of which 76.3% involved uncertainty regarding previous ATC instructions. That is, they included transmissions such as "CONFIRM THAT WAS TWENTY EIGHT POINT ONE FIVE," "VERIFY THAT'S UP TO THREE THREE ZERO," and "SAY AGAIN SECONDARIES."

Table 10 shows that 81.2% of the pilots' responses contained full readbacks of the controller instructions, advisories, or both. Whereas in Cardosi's 1993 report, full readbacks occurred for 71% of previously issued ATC messages, the data presented here indicate a 10.2% increase in full readbacks with a corresponding decrease in partial readbacks — down from 12% in the Cardosi report to 7.9%. We took the category 'Other Replies' which constituted another 8% of pilot responses in the Cardosi report and split it into 'Other Replies' and 'Courtesy.' Together, they accounted for 3.3% of the pilot responses. Only 2.8% of the pilots responded with an acknowledgment only.

Of the 3.8% ATC messages that received no pilot acknowledgement, 91.9% of them had one (86.3%) or two (5.6%) instructions while another 5.0% involved only altimeter settings. Of the unacknowledged single-topic instructions, 49.0% involved changes to radio frequency. Altitude (16.0%), transponder (11.0%), heading (5.0%), route/position (8.0%), speed (6.0%), and altitude restriction (5.0%) comprised the remainder of unacknowledged single-topic instructions. The remaining 3.1% unacknowledged messages were a combination of instructions and advisories that contained two (2.5%) or more than two topics (0.6%).

Pilot Use of Call Signs in Readbacks. The types of call signs used by pilots and their representative examples are shown in Figure 4. In Table 11, the frequency distributions of the usage of the various types of call signs are presented by their rate of occurrence as a function of pilot responses to 4,261 ATC messages.

Table 11 shows that pilots provided either a complete (74.5%) or partial (14.5%) call sign in 89% of their responses to ATC. Production of incorrect call signs constituted 1.3% of their responses. There were 59 transmissions where pilots provided incorrect call signs (replacement of the assigned call sign with that of another). In 27 of these transmissions, the incorrect call signs resulted from importing numbers or letters not found in the actual call sign. For example, the pilot of Ownship 2577 responded with, "OWNSHIP TWENTY TWENTY-SEVEN." In 32 other transmissions, pilots omitted some numbers either at the beginning (Ownship 049 was called 'OWNSHIP FOUR NINE'), middle (Ownship 901 became 'OWNSHIP NINETY ONE'), or at the end of the call sign (OWNSHIP 1512 became 'OWNSHIP FIFTEEN') failed to include the prefix ('OWNSHIP'), or gave only a partial prefix.

Analysis of Pilot Faulty Readback Performance

As noted in Table 11, 89% of the selected controller transmissions were responded to with either a full or partial readback. Of these 3,799 readbacks, 28.7% (n=1,089) were read back correctly, complete with all anchor words. The remaining 71.3% faulty readbacks

Table 10. Pilot Responses to ATC Messages.

Types of Pilot Response	Types of ATC Messages: Instructions Only	Altimeter Only	Instructions and Altimeter	Percent of all Messages
Full Readback	76.6%	1.4%	3.1%	81.2%*
Partial Readback	6.4%	.1%	2.2%	8.6%
Acknowledgment Only	2.5%	.2%	.0%	2.8%
Other Replies	2.5%	.0%	.3%	2.8%
Courtesy	.4%	.1%	.0%	.5%
No Acknowledgment	3.3%	.2%	.1%	3.8%
Blocked	.3%	.0%	.1%	.4%
Table Total	92.1%	2.1%	5.8%	100.0%

*Subject to rounding error

Call Sign Usage	ACID	Example
Complete	UAL56H	UNITED FIFTY SIX HEAVY
Partial		
Prefix w/ some numbers/letters Inc. prefix w/ all numbers/letters No prefix w/ all numbers/letters No prefix w/ some numbers/letters	DAL884 ACA1017 TRS467 GWY256	DELTA EIGHTY FOUR CANADA TEN UH SEVENTEEN FOUR SIXTY SEVEN FIFTY SIX
Incorrect call sign	N21828CG	TWO CHARLIE GOLF
Unintelligible	AAL538	AMER (UNINTELLIGIBLE)
No call sign		

Figure 4. Examples of Various Types of Pilot Call Sign Usage.

Table 11. Pilot Call Sign Usage as a Function of the Type of Pilot Response.

Pilot Call Sign Usage	Type of Pilot Response						Percent
	Full Readback	Partial Readback	Ackn. Only	Other Replies	Courtesy	Blocked	
Complete	63.6%	7.3%	1.6%	2.0%			74.5%
Partial	12.8%	.8%	.5%	.4%			14.5%
Incorrect call sign	.9%	.3%	.1%				1.3%
Unintelligible	.1%	.1%					.2%
No call sign	6.3%	.4%	.9%	1.4%	.6%	.4%	10.0%
Table Total	83.7%	8.9%	3.1%	3.8%	.6%	.4%	100.5%*

* Rounding errors

were categorized according to three types of errors: Errors of omission only (67.4%), Readback errors only (0.9%), and Readback errors combined with Errors of omission (3.1%). Pearson correlations revealed that errors of omissions increased significantly as the complexity, r (3799) = .46 and message length (i.e., number of ATs), r(3799) = .29 in a controller's message increased, $p<.05$. Similarly, the number of readback errors in a transmission increased with its complexity, r (3799) = .11 and length, r (3799) = .14, $p<.05$.

Pilot Errors of Omission. Readbacks are predicated on the *Aeronautical Information Manual* § 4-4-6b, which suggests that the pilot read back the numbers in altitude assignments or vectors. *FAA Order 7110.65* § 2-4-3 instructs the controller to verify the accuracy and completeness of any readback. § 2-4-3, while instructing the controller to ensure the completeness, has by common usage and knowledge omitted frequency readbacks from this requirement. This is a logical move in communication, as the frequency band used throughout these transcriptions is in the 100 range, i.e., a readback of a frequency instruction "ONE ONE NINE POINT TWO FIVE" read back as "ONE NINE TWO FIVE" would be considered an error of omission (i.e., failure to include the anchor 'POINT' or 'DECIMAL' but NOT a readback error.

Errors of omission were classified into three types: (1) exclusion of anchor words (absence of 'POINT' in a radio frequency, 'FLIGHT LEVEL' or 'THOUSAND' in altitude, etc.), (2) exclusion of some digits (in response to "CONTACT CENTER ONE ONE NINE POINT TWO FIVE," the pilot replies "POINT TWENTY FIVE"), and (3) the exclusion of anchor word(s) and digit(s) (in response to "CONTACT CENTER ONE ONE NINE POINT TWO FIVE," the pilot replies "NINE TWENTY FIVE").

There were 2,559 pilot faulty readbacks that contained errors of omission. The data presented in Table 12 under the column labeled "Percentages of all Pilot Transmissions" were computed using the 3,799 full and partial readbacks in the denominator (e.g., 2,506/3,799), while data in the column labeled "Percentage of Transmissions with Omissions" used the 2559 faulty readbacks in the denominator (e.g., 2,506/2,599). When pilots attempted either a full or partial readback, 67.4% of their readbacks contained one or more errors of omission. Of these omissions, nearly 98% involved the absence of an anchor word.

Aviation Topics with Errors of Omission. Table 13 presents the distribution of errors of omission according to the types of ATs read back incorrectly. Column (a)

Table 12. Prevalence of Pilot Transmissions with Errors of Omission.

Types of Omission Errors	Number of Readbacks	Percentage of all Pilot Transmissions	Percentage of Transmissions with Omissions
Omit anchor word (s)	2506	66.0%	97.9%
Omit digit (s)	9	.2%	.4%
Combination of both	44	1.2%	1.7%
Total	2559	67.4%	100.0%

Table 13. Distribution of Pilot Errors of Omission by Aviation Topic.

Type of Aviation Topic	Number of AT in all Pilot Readbacks (a)	Number of Errors of Omission (b)	Proportion of Errors of Omission (c)	Percentage of Errors of Omission (d)
Altimeter	244	185	6.83	75.82
Altitude	1394	933	34.44	66.93
Altitude restriction	396	255	9.41	64.39
Heading	205	109	4.02	53.17
Holding	9	1	0.04	11.11
Radio frequency	1158	876	32.34	75.65
Route/Position	650	134	4.95	20.62
Speed	276	154	5.68	55.80
Transponder	102	62	2.29	60.78
Total	4434	2709	100.00	

presents the number of ATs read back in all of the 3,799 pilot readbacks. Column (b) presents the total number of omission errors contained in the 2,559 pilot transmissions with one or more omissions. The proportion of omission errors that are presented in Column (c) was computed using the number of instances a particular aviation topic was read back with an omission divided by the total number of errors of omission (e.g., Altimeter readback errors = 185/2,709*100).

Column (c) of Table 13 shows that 43.85% of the 2,709 identified omission errors involved an altitude (34.44%) or altitude restriction (9.41%). Changing to another radio frequency captured an additional 32.34% of the errors of omission. The remaining 24% errors of omission were fairly well distributed among altimeter, speed, route/position, and heading instructions, with transponder and holding instructions accounting for less than 3% of these errors of omission.

The percentages presented in Column (d) were computed by dividing the number of instances that a particular aviation topic was read back incorrectly by the total number of readbacks of that aviation topic found in Column (a) (e.g., Altimeter readback errors = 185/244*100). It shows that slightly more than 75% of altimeter and radio frequency ATs contained errors of omissions, followed by more than 60% of the altitude, altitude restriction, and transponder readbacks, and greater than 50% of the heading and speed assignments. Pilots were less likely to omit some of the contents of their readback of holding and route/position instructions.

Pilot Readback Errors. During periods of heavy traffic, radio frequency congestion is often cited as a problem affecting communication efficiency (Data Link Benefits Study Team, 1995). Following the delivery of an ATC transmission, the controller listens for the pilot to read back accurately the original message. The presence of a mistake is called a readback error. Failure to detect a readback error is a hearback error. Improperly phrased readbacks that contain the correct information are not readback errors.

Each pilot readback was evaluated for accuracy. Also, the type of readback error and the number of readback errors were recorded (e.g., a zero indicated no error, while a value of 3 indicated three errors). Also examined was the prevalence of pilot readback errors as a function of ATC message complexity and message length. Each ATC transmission that met the selection criterion (i.e., it contained an instruction, an advisory, or a combination of instruction and advisory) was paired with the pilot's response to that transmission. When a pilot read back the contents of a controller's transmission, the same criteria found in *FAA Order 7110.65* was applied to the evaluation of that readback.

The results presented in Table 14 were derived from 151 pilot transmissions with one or more substitutions, transpositions, or their combination with errors of omission. The data presented under the column labeled "Percentages of All Pilot Transmissions" were computed using the 3,799 full and partial readbacks in the denominator, while data in the column labeled "Percentage of Transmissions with Readback Errors" used the 151 pilot transmissions with readback errors in the denominator. Four percent of the pilots' readbacks contained one or more readback errors, of which 78% resulted from a combination of an error of omission with one or more substitution (89%) or transposition (11%) errors.

Aviation Topics With Readback Errors. Table 15 presents the distribution of readback errors according to the types of ATs read back incorrectly. Column (a) presents the number of ATs read back in all of the 3,799 pilot readbacks. Column (b) presents the total number of readback errors contained in the 151 pilot transmissions containing one or more readback error. The proportion of readback errors presented in Column (c) was computed using the number of instances a particular aviation topic was read back incorrectly divided by the total number of readback errors (e.g., Altimeter readback errors = 15/162*100).

Table 14. Prevalence of Pilot Transmissions With Readback Errors.

Type of Readback Error	Number of Transmissions with Readback Error (s)	Percentage of All Pilot Transmissions	Percentage of Transmissions with Readback Errors
Transposition	3	.1%	2.0%
Substitution	30	.8%	19.9%
Combination of readback error types	118	3.1%	78.1%
Total	151	4.0%	100.0%

Table 15. Distribution of Pilot Readback Errors by Aviation Topic.

Type of Aviation Topic	Number of AT in all Pilot Readbacks (a)	Number of Readback Errors (b)	Proportion of Readback Errors (c)	Percentage of Readbacks in Error (d)
Altimeter	244	15	9.26	6.15
Altitude	1394	36	22.22	2.58
Altitude restriction	396	23	14.20	5.81
Heading	205	9	5.56	4.39
Holding	9	2	1.23	22.22
Radio frequency	1158	49	30.25	4.23
Route/Position	650	17	10.49	2.62
Speed	276	9	5.56	3.26
Transponder	102	2	1.23	1.96
Total	4434	162	100.00	

Column (c) of Table 15 shows that 30.25% of the 162 identified readback errors involved an instruction to change to another radio frequency. Altitude and altitude restrictions captured an additional 36.42% of the readback errors. Route/position clearances were read back incorrectly 10.49%, altimeter contributed another 9.26%, while heading and speed instructions each added another 5.56% to the total proportion of readback errors. Finally, holding and transponder instructions captured the remaining readback errors. These findings replicate those of Cardosi (1993) who reported radio frequency, followed by crossing restrictions, altitude, and altimeter ATs were the most common readback errors.

The results presented in column (c) of Table 15 fail to take into account the frequency of delivery of those ATs by controllers. There may be more opportunities to incorrectly read back a radio frequency or altitude instruction simply because controllers issued them more often. Therefore, another analysis was performed that compared the number of readback errors of a particular aviation topic (e.g., altimeter) to the total number of readbacks of that AT. The percentages presented in Column (d) were computed by dividing the number of instances that a particular aviation topic was read back incorrectly by the total number of readbacks of that aviation topic found in Column (a) (e.g., Altimeter readback errors = 15/244*100). The data show that 22% of the holding instructions were read back incorrectly, although they were few in number.

Message Complexity and Pilot Readback Performance. As seen in Figure 5, pilots read back correctly 72% of the ATC messages that had a CL that was no greater than 3, and their performance dropped to less than 15% accuracy once the CL of an ATC message increased to 7 or greater. To determine whether the increase in faulty readbacks was statistically reliable, ANOVAs were conducted separately on errors of omission and readback errors.

The number of pilot errors of omission and number of readback errors were aggregated by facility, sector, and complexity value. The One-Way ANOVA revealed that Message Complexity had a statistically significant effect on the production of errors of omission [$F(4,89) = 52.41$] but not readback errors [$F(4,89) = 1.97$]. As seen in Figure 6, Fisher LSD post hoc comparisons revealed a steady increase in the mean number of errors of omission as the complexity value of ATC messages increased. The mean number of omission errors were comparable at CL 6 and CL 7 only [(CL 8 > CL 7, CL 8 > CL 6, CL 8 > CL 4-5, and CL 8 > CL ≤ 3); (CL 7 = CL 6, CL 7 > CL 4-5, CL 7 > CL ≤ 3); (CL 6 > CL 4-5, CL 6 > CL ≤ 3); (CL 4-5 > CL ≤ 3)].

Message Length and Pilot Readback Performance

The number of pilot errors of omission and number of readback errors were aggregated according to the facility, sector, and message length. The One-Way ANOVA revealed that Message Length affected the production of errors of omission [$F(2,45) = 5.97$] and readback errors [$F(2,45) = 3.61$]. As seen in Figure 7, Fisher LSD post hoc comparisons revealed more errors of omission as ATC message length increased from one to two or more aviation topics, [(NAT 3-4 > NAT 2, NAT 3-4 > NAT 1); (NAT 2 = NAT 3-4)]. Likewise, an examination of the mean number of pilot readback errors using Fisher LSD post hoc comparisons indicates a statistically significant increase in the production of pilot readback errors once ATC message length exceeds two aviation topics, [(NAT 3-4 > NAT 2, NAT 3-4 > NAT 1; NAT 3-4 = NAT 2)].

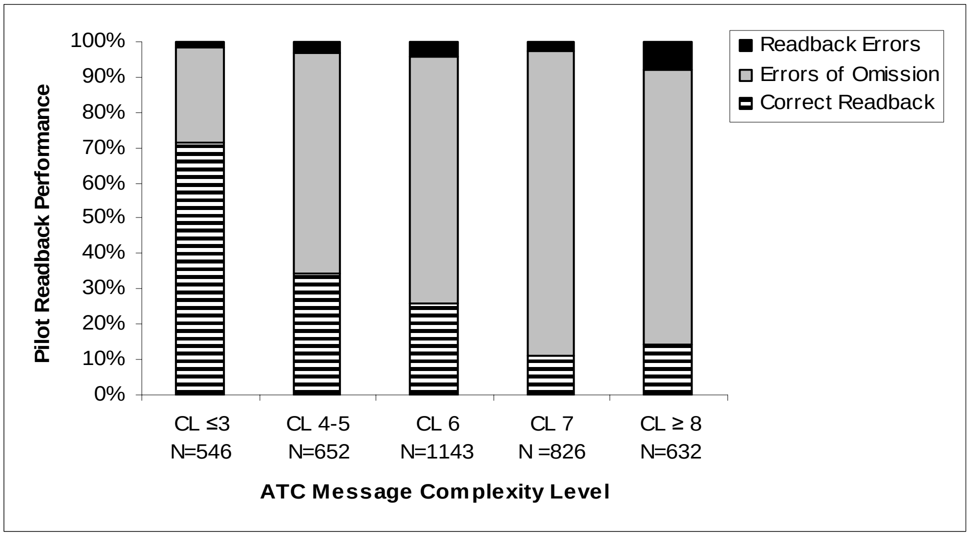

Figure 5. Pilot Readback Accuracy Presented by ATC Message Complexity.

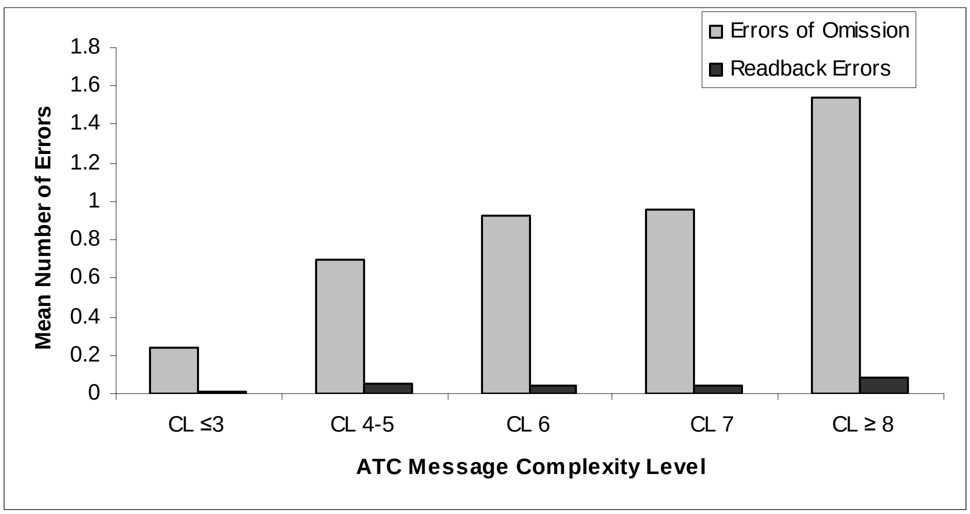

Figure 6. Mean Number of Pilot Omission and Readback Errors Presented by Message Complexity.

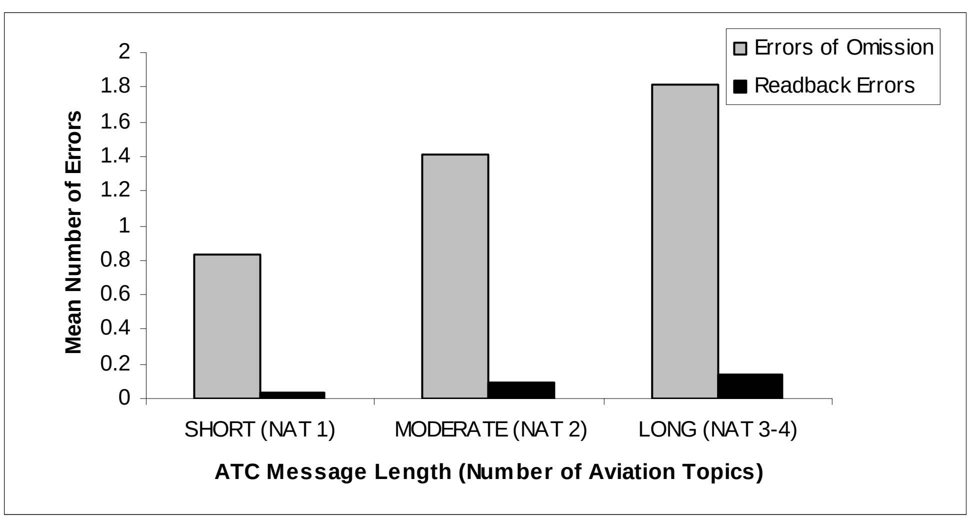

Figure 7. Mean Number of Pilot Omission and Readback Errors Presented by Message Length.

Analysis of Pilot Requests for Repeat of an ATC Transmission

There are times while pilots are busy completing checklists or performing other station-keeping tasks when they hear, or think they hear, their aircraft's call sign and will ask ATC if they are calling them. At other times, uncertain of the accuracy of an attempted readback, they may request a repeat of all (say again) or part (what was that heading again) of the message. In still other instances, they may request confirmation of the aviation topics that they thought they heard (confirm we're cleared down to ten thousand).

There were 112 requests for ATC to repeat an earlier transmission. We identified four different types of requests: (1) 25% requests for the repetition of a specific AT, (2) 23.2% requests for the repetition of an entire transmission, (3) 39.3% confirmation/verification of a specific AT, and (4) 12.5% confirmation that the transmission was for them.

Requests for Repeat of a Specific AT. A detailed examination of 28 pilot transmissions requesting that ATC repeat a specific aviation topic is presented in Figure 8. It shows that route clearances (43%) and instructions to switch to another radio frequency (29%) were more frequently requested "say agains" than altimeter (11%), speed (7%), altitude (4%), altitude restriction (4%), and transponder assignments.

Types of Aviation Topics Requested: Message Length and Complexity. A more comprehensive examination of the pilot and controller pairs was performed that took into account both ATC message length and complexity value. It revealed that when messages were short (NAT = 1) and less complex (CL $\geq$ 3) only radio frequencies (n = 1) and route (n = 7) were requested. When messages were still short but somewhat complex (CL = 6-7), pilots requested radio frequencies (n = 6) and a route clearance be repeated (n = 1). There was only one repeat request for a short message that was considered high in complexity (CL ≥ 8), and it was a route clearance.

As ATC messages increased to a moderate length (NAT = 2) but were less complex (CL ≤ 3), there were no say agains for a specific aviation topic. There was one 'SAY AGAIN ALTITUDE' for an ATC message that was somewhat complex (CL = 6-7). Messages that were high in complexity (CL ≥ 8) had one request each for the repetition of an altitude restriction, speed, radio frequency, and transponder; two requests for a route; and three requests for the altimeter.

For long ATC messages (NAT = 3), requests for repeats only occurred for complex messages from ATC (CL ≥ 8). There was one each for speed and route.

Requests for the Repetition of an Entire Transmission. There were 26 pilot requests to have ATC repeat an entire message. When the ATC transmission was short (NAT = 1) and increased in complexity, there was a general increase in the number of 'say agains' (CL ≤ 3 n= 3; CL = 4-5, n = 2; CL = 6-7, n = 12; CL ≥ 8, n = 3). This same pattern was present for moderate length ATC Messages (CL = 6-7, n = 1; CL ≥ 8, n = 3) and for long messages (CL ≥ 8, n = 2).

Confirmation/Verification of a Specific AT. There were 44 pilot requests for confirmation for a specific aviation topic. Figure 9 shows that the more frequently requested confirmations involved radio frequency (27.3%) and altitude (22.7%) assignments, route clearances (25.0%), and altitude restrictions (11.4%). Infrequent were confirmations that involved altimeter and transponder settings (each 2.23%) or heading and holding instructions (each 2.23%).

Types of Aviation Topics Requested: Message Length and Complexity. A closer examination of pilot requests for confirmation also took into account ATC message length and complexity value. It revealed that when messages were short and less complex (NAT = 1, CL $\leq$ 3),

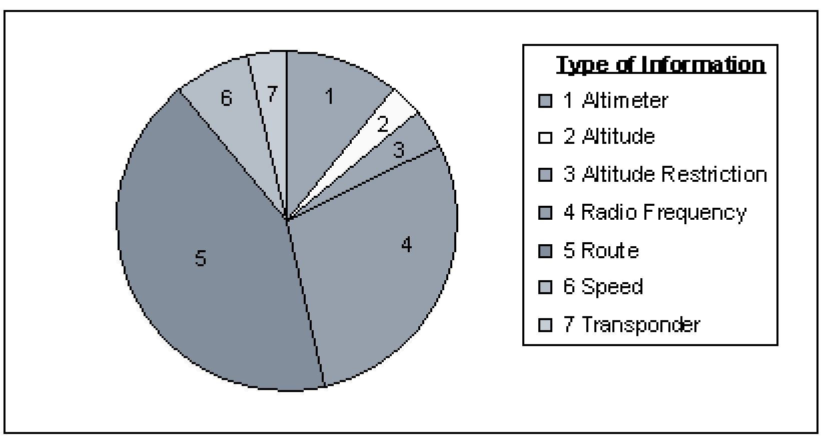

Figure 8. Requests for Repeat.

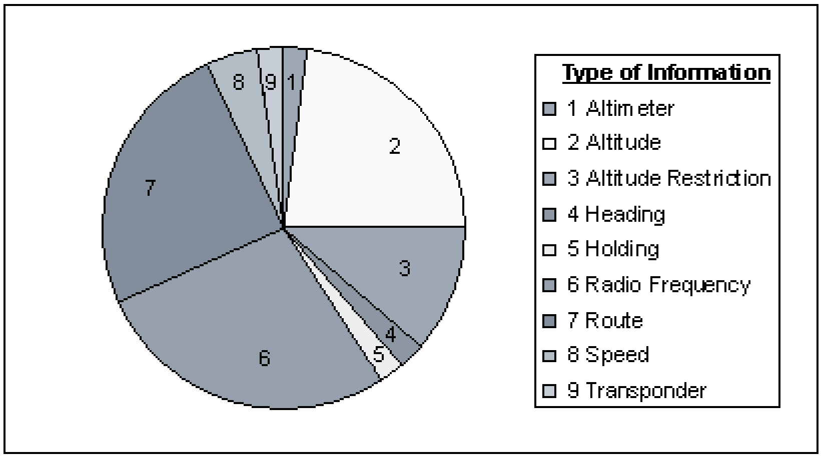

Figure 9. Requests for Clarification.

pilots wanted confirmation of their route (n = 6), altitude restriction (n = 2), altitude (n = 1), and transponder (n = 1). When messages were still short but increased slightly in complexity (CL = 4-5), pilots again wanted confirmation of their speed (n = 2), route (n = 1), and altitude (n = 1) assignments. Short but somewhat complex ATC messages (CL = 6-7) entailed confirmation for radio frequency (n = 12), altitude (n = 5), route (n = 2), and heading (n = 1) aviation topics. There were no requests for short messages that were considered high in complexity.

As ATC messages became moderate in length (NAT = 2) and were somewhat complex (CL = 6-7), there were requests for confirmation of an altitude (n = 2) and a route (n = 1). Once ATC messages were high in complexity, pilots made three requests for the repetition of an altitude restriction and one request each for altitude, altimeter, holding, and route. There were no requests for the confirmation of any ATs for long messages.

Pilots Request Confirmation That the Transmission was for Them. There were 14 pilot requests that the controller confirm that the preceding message was for them. The message pair generally took the form of ATC sending a message to Ownship1234 and the pilot replying with "… THAT FOR OWNSHIP 1234?" Of these queries, five were in response to the controller calling Ownship1234, but with an incorrect call sign. Each of these ATC messages were short (NAT = 1) but varied in complexity (CL ≤ 3, n = 1; CL = 4-5, n = 1; and CL = 6-7; n = 3).

There were seven other ATC short (NAT = 1) transmissions that varied in complexity (CL ≤ 3, n = 3; CL = 4-5, n = 1; CL = 6-7; n = 2; CL ≥ 8, n = 1). Finally, there were two ATC transmissions of moderate length that were high in complexity (CL ≥ 8). For all of these 14 requests, rather than executing an instruction that might have been intended for another aircraft, the pilot appropriately questioned the controller.

DISCUSSION

The results presented in this report provide a description and summary of the controller-pilot communication process that occurred during normal, day-to-day operations in the en route environment. Five different geographical areas in the contiguous United States were contacted for 10 hrs each of pilot-controller voice communications that resulted in the analysis of 51 hrs of communications. Both U.S. and foreign registry aircraft were represented, as well as general aviation aircraft. On average, across the five sampled ARTCC facilities, one aircraft requested and received air traffic services every 2 min 4 s. The number of ground-to-air transmissions averaged 4.62 messages per aircraft and approximately 10 messages were exchanged (from initial contact until the aircraft was switched to the next controller in sequence) that involved an allocation of about 28 s of airtime per aircraft. The most frequently transmitted instructions involved changes in altitudes and switching pilots to another radio frequency.

Unlike the findings reported by Cardosi (1993), where 78% of the ATC messages involved one or two pieces of information, we found that less than 1% of the controllers' messages did. In fact, our data revealed that 51% of the controllers' transmissions had a Complexity Level = 6-7 and generally ranged from very low (CL = 2) to very high (CL = 31) in complexity. The messages very high in complexity involved route clearances. The number of aviation topics (message length) was more in keeping with Cardosi's approach to determining message complexity. In this report, short messages with only one aviation topic occurred in 84% of the controllers' transmissions, and messages with two aviation topics occurred in 14% of the transmissions.

The disparity between these reports resides partially in how the concept of message complexity was measured. For Cardosi (1993), the ATC transmission "contact Minneapolis Center 118.8" (p3) was considered one piece of information if the pilot was already on a Minneapolis Center frequency and as two pieces of information if the pilot received it while communicating with a different ARTCC. Prinzo et al. (2006) considered the same transmission to contain one communication element — radio frequency —and it had a complexity value of 6. The rationale was that each digit comprising the radio frequency imposed a memory load that could result in the pilot erroneously reading back the wrong facility/function, omitting, transposing, or substituting any (or all) of the digits in the radio frequency, or both.

Since the publication of Cardosi's 1993 report 15 years ago, we report a 10.2% increase in full readbacks and a 3.4% decrease in partial readbacks. It is of no surprise then that there is also a decline in replies such as 'ROGER,' 'SEE YA,' and 'THANKS' in lieu of full and partial readbacks. This is encouraging because 'ROGER' and 'THANKS' fail to provide the controller with confirmation that the instruction/clearance, advisory, and related information was received and understood by the pilots. Unfortunately, both reports show no change in the number of ATC transmissions that went unacknowledged (3%).

Also encouraging to improvements in aviation safety is the trend among pilots to include either their full or a partial call sign as part of their readbacks. Controllers should never have to infer the identity of a pilot from voice qualities alone. Overall, pilots included either a complete or partial call sign in 89% of their readbacks. Moreover, pilots who provided a full readback also included the complete call sign in approximately 64% of their responses. The fact that call signs were excluded in 10% of their readbacks and 0.2% of the spoken call signs were unintelligible leaves room for improvement. The use of an incorrect call sign was infrequent — occurring in 1.3% of their responses to ATC. In approximately 45% of these instances, pilots either included some numbers or letters that were not part of their call sign; while in the remaining 55%, numbers or letters were omitted.

As noted previously, 71.3% of the pilot responses to ATC contained faulty readbacks, of which 67.4% contained one or more errors of omission. The increase in faulty readback performance was attributed to a steady rise in errors of omission brought on by the added complexity of ATC messages. This is not altogether surprising, given the high memory load imposed on the pilot's working memory capacity and the fact that verbatim recall of ATC messages is not a requirement. It seems that pilots shed the redundant words present in aviation topics that were not altogether necessary for navigating the flight plan. This is comparable to retaining the gist of a conversation rather than its exact wording. Omitting non-essential words during readback still preserves the identity of the aviation topic and has no adverse affect on pilot's actions (Barshi & Healy, 2002).

The remaining 4% faulty readbacks contained at least one readback error. An examination of these faulty readbacks revealed that less than 1% involved readback errors only. The remaining 3.1% faulty readbacks involved the combination of an error of omission coupled with one or more substitution (89%) or transposition (11%) readback errors. Unlike message complexity, message length affected both the production of errors of omission and readback errors. There were more errors of omission as ATC message length increased from short (one aviation topic), to moderate (two aviation topics), and long (three or more aviation topics). Redundant information might be eliminated to increase the economy of capacity limitations of verbal working memory.

Readback errors increased once ATC messages included two or more aviation topics. The most common readback errors involved altitude and altitude restrictions, followed by radio frequency, route/position clearance, and altimeter settings. These findings agree with research investigating the capacity limitations of verbal working memory that suggest that the upper limit for propositional representations (Barshi & Healy, 2002) and sentence processing (Lewis, 1996) is three.

Some of the pilot readbacks that were scored as readback errors involved pilot use of slang. That is, an ATC instruction to 'CONTACT CENTER ON ONE ONE NINER POINT ZERO,' was occasionally read back as 'NINETEEN ZIP' or 'NINETEEN NOTHING.' Clearly, 'NINETEEN NOTHING' and 'NINETEEN ZIP' are not part of the ICAO alphabet or aviation accepted pronunciation of numbers. Both readbacks are examples of substitution errors (and omission of the anchor word 'POINT'). What is worrisome about these readbacks is that other pilots may hear the slang and not understand what the pilot intends to do (especially pilots who are less proficient in aviation English).

There were several pilots who chose to read back flight levels in thousands of feet — the ATC instruction 'DESCEND AND MAINTAIN FLIGHT LEVEL ONE NINE ZERO' read back as, 'NINETEEN THOUSAND,' or 'TO LEVEL ONE NINE.' Instructions to 'REDUCE SPEED TO TWO FIVE ZERO' read back as 'TWO FIVE' or 'DOWN TO TWO FIVE ZERO' are ambiguous and subject to misinterpretation. Again, these examples illustrate substitution errors made during read back that may have adverse affects on safety.

The low number of pilot requests for the repeat of an ATC transmission was particularly encouraging. Possibly to avoid the risk of either reading back the contents of an ATC transmission meant for another aircraft (stolen

transmission) or reading back the contents incorrectly (readback error), pilots asked the controller for either a full or partial repeat of the original message. Of these 112 pilot requests, five involved a call sign misspoken by the controller to which the pilot wanted confirmation that the message was for them. Of the remaining 107 requests, 37% involved the repetition of the entire transmission. A closer look at these transmissions showed that 67.5% had either a fix/intersection or facility name included as part of their content[3] — and many of these messages involved route clearances and the transfer of communications.

The inspection of the ATC messages that pilots wanted confirmed or repeated revealed that many of these messages also involved route clearances that varied in complexity from less complex (CL ≤ 3 CLEAR DIRECT [NAME]) to high in complexity [CL ≥ 8 FLY HEADING THREE FOUR ZERO / INTERCEPT THE [NAME] ONE SIX TWO RADIAL TRACK INBOUND JOIN THE [NAME] FIVE ARRIVAL OFF THAT]. In both examples, pilots asked for the name of the fix/intersection, the name of the radial, name of the arrival route, etc. Clearly, the names of location identifiers, fixes, intersections, navigational aides, etc. are critical to navigation; and the pilots were prudent in requesting either the repetition or confirmation of previously heard identifiers.

Likewise, the same pattern of results was found when pilots requested that a radio frequency be repeated or confirmed. In such instances, radio frequencies were somewhat complex (CL = 6-7) and varied according to whether the name of the facility was included, along with the numbers in the radio frequency and the number of digits following the anchor 'point' (CONTACT [NAME] CENTER ON ONE THREE FOUR POINT FIVE FIVE) or not (CONTACT CENTER ON ONE THREE FOUR POINT FIVE FIVE or CONTACT [NAME] CENTER ON ONE TWO FOUR POINT SEVEN).

Based on the findings in this report, it is recommended that:

1) No more than three aviation topics are present in any ATC transmission. The review of the literature and the findings of this report indicate an increase in readback errors is more likely with increases in message length;
2) If a route clearance is given, that it should be given separately as a stand-alone transmission. This is especially important when complex route clearances are transmitted by ATC. The findings in this report show that as the complexity of an ATC message increases, so does the frequency of errors of omission during readback;
3) The names of all fix, waypoint, location, etc., identifiers be repeated, and if necessary, spelled out following their first recitation; for example, 'CLEARED DIRECT COBAD THAT'S CHARLIE OSCAR BRAVO ALFA DELTA,' or 'CLEARED DIRECT COBAD C-O-B-A-D.' This could aid pilots flying for non-U.S. registry airlines who may not be familiar with how U.S. identifiers are pronounced. Likewise, sometimes the spelling of a location identifier is not intuitive, or in agreement with its pronunciation (e.g., CVE = Cowboy). In such cases, the controller may want to spell out the 3-letter identifier to aid pilots in locating it on their maps;
4) Slang should not be accepted as part of a pilot readback. There is a degree of uncertainty when slang is introduced into the recitation of an ATC message. Ambiguity creates doubt and compromises safety;
5) Effort be undertaken to reduce excessive words/phrases — on, your, to, is, etc. The phraseology created by the FAA is precise and needs no further embellishment.

As part of its modernization programs, the FAA, along with avionics developers, may want to consider building messages sets for complex messages and send them via a datalink. Likewise, the more routine ATC messages could be up-linked to the flight deck computers according to application. For example, route clearances that contain the names of all fix, waypoint, location, and other identifiers could be up-linked to a navigation display (e.g., moving map) for pilot consideration and then either accepted, rejected, or negotiated. Traffic advisories could be displayed on an ADS-B/CDTI (automatic dependent surveillance broadcast/cockpit display of traffic information). Also, by changing the representation of the message away from text to graphic, complexity becomes simplified and easier to process.

[3] See FAA JO 7400.2G. *Procedures for Handling Airspace Matters* (April 10, 2008) for details involved in naming conventions and references to other FAA Orders.

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APPENDIX A

Guide to the Computation of Complexity: ATC Instruction/Clearance Aviation Topics

(*Minimum-Maximum Values)

AVIATION TOPIC	COMPLEXITY	PHRASEOLOGY
ALTITUDE		4=FLIGHT LEVEL + *(altitude) three digits*
		3=*(altitude) two digits* +THOUSAND
		2=*(altitude) one digit* + THOUSAND
		3=*(altitude) two digits* + HUNDRED
		2=*(altitude) one digit* + HUNDRED
		2=*(altitude) two digits*
		1=*(altitude) one digit*
	6	DESCEND/CLIMB & MAINTAIN *(altitude)* THOUSAND *(altitude)* HUNDRED
	6	*three five*
		DESCEND/CLIMB & MAINTAIN *(altitude)* THOUSAND *(altitude)*
	6	THOUSAND
		one two *twelve*
	5	DESCEND/CLIMB & MAINTAIN FLIGHT LEVEL *(altitude)*
		two three zero
	4	DESCEND/CLIMB & MAINTAIN *(altitude)* THOUSAND
		one zero
	*4-8	DESCEND/CLIMB & MAINTAIN *(altitude)* THOUSAND
	*4-8	*four*
	*3-7	CONTINUE CLIMB/DESCENT TO *(altitude)*
	*3-6	AMEND YOUR ALTITUDE DESCEND/CLIMB MAINTAIN *(altitude)*
	*2-5	AMEND YOUR ALTITUDE MAINTAIN *(altitude)*
	*1-3	DESCEND/CLIMB TO *(altitude)*
		MAINTAIN *(altitude)*
		(*altitude*, omitted "THOUSAND" "HUNDRED" "FLIGHT LEVEL")
ALTITUDE RESTRICTION		4=FLIGHT LEVEL + *(altitude) three digits*
		3=*(altitude) two digits* + THOUSAND
		2=*(altitude) one digit* + THOUSAND
		3=*(altitude) two digits* + HUNDRED
		2=*(altitude) one digit* + HUNDRED
		2=*(altitude) two digits*
		1=*(altitude) one digit*
	*4-7	EXPEDITE CLIMB/DESCENT THROUGH/TO *(altitude)*
	*4-7	CROSS *(point)* AT/ABOVE/BELOW *(altitude)*
	*4-7	MAINTAIN *(altitude)* UNTIL *(point)*
	*3-7	*(altitude)* TIL ESTABLISHED/LOCALIZER/ESTABLISHED ON
	*3-7	LOCALIZER
	*3-6	INCREASE/DECREASE RATE OF DESCENT THROUGH (*altitude)*
	*3-6	EXPEDITE THROUGH/TO *(altitude)*
	2	*(point)* AT *(altitude)*--*(altitude)* TIL (*point)*--HURRY DOWN TO *(altitude)*
	2	*(Speed assignment)* **"<u>THEN</u>"** DESCEND/CLIMB
	1	INCREASE/DECREASE RATE OF DESCENT
	1	GOOD RATE DOWN/YOUR BEST RATE
		EXPEDITE CLIMB/DESCENT -- CLIMB/DESCEND NOW

AVIATION TOPIC	COMPLEXITY	PHRASEOLOGY
APPROACH/ DEPARTURE	6	CLEARED ILS RWY *(name)* R/C/L APCH
	6	CLEARED VISUAL APCH RWY *(name)* R/C/L
	5	CLEARED ILS/VISUAL RWY *(name)* R/C/L
	5	CLEARED ILS/VISUAL *(name)* R/C/L APCH
	4	CLEARED ILS RIGHT/LEFT/CENTER APCH
	3	ILS RIGHT/LEFT/CENTER APCH
	3	CLEARED ILS *(name)*
	3	CLEARED RWY *(name)*
	2	CLEARED APCH
	2	CLEARED *(type)*
	2	ILS RIGHT
	2	RWY *(name)*
	2	CLEARED VISUAL/ILS
DISREGARD		NOT INCLUDED IN COMPLEXITY
GENERAL ACKNOW.		NOT INCLUDED IN COMPLEXITY
HEADING	4	TURN LEFT/RIGHT HEADING *(degrees)*
	4	TURN *(degrees)* DEGREES LEFT/RIGHT
	3	TURN LEFT/RIGHT *(degrees)*
	3	DEPART (*fix*) HEADING (*degrees*)
	3	FLY HEADING *(degrees)*
	2	FLY PRESENT HEADING
	2	HEADING *(degrees)*
	1	*(degrees)*
HEADING MODIFICATION	2	INCREASE RATE OF TURN
	2	GOOD LEFT/RIGHT TURN
	1	TIGHT TURN
HOLDING	11	HOLD (*direction*) OF (*fix/waypoint*) ON (*specified radial, course, bearing, track, airway, azimuth(s), or route*) (*number of minutes/miles*) MINUTE/MILE LEG
	8	HOLD (*direction*) OF (*fix/waypoint*) STANDARD PATTERN
	4	HOLD SHORT RUNWAY *(number)*)
	3	EXPECT FURTHER CLEARANCE (*time*)
	1	HOLD
RADIO FREQUENCY	*6-7	CONTACT *(facility/function) (frequency + point)* – could be up to four digits in frequency (2 on either side of "point")
	*5-7	(*facility/function) (frequency + point)/(facility/function) (frequency w/o point)*
	*4-5	*(frequency + point)*
	*3-4	*(frequency)*
	3	FREQUENCY CHANGE APPROVED
	3	CHANGE TO ADVISORY/MY FREQUENCY APPROVED
	2	CONTACT *(facility/function)*
	1	*(facility/function)*
	1	*(change point, e.g. now, there, at/over marker/when established)*

AVIATION TOPIC	COMPLEXITY	PHRASEOLOGY
ROUTE/ POSITION	*5-7	DIRECT *(fix) (airway, course, localizer, arrival/departure, etc.)*
	5	INTERCEPT/JOIN RUNWAY *(name)* LEFT/RIGHT LOCALIZER
	*3-5	INTERCEPT/JOIN/RESUME *(airway, course, localizer, arrival/departure,*
	4	*etc.)*
	3	TURN LEFT/RIGHT DIRECT *(point/fix)*
	3	MAINTAIN VISUAL FROM THAT TRAFFIC/HIM/THEM/MD80
	2	KEEP HIM IN SIGHT
	2	MAINTAIN VISUAL SEPARATION
	2	DIRECT *(fix)*
	2	FOLLOW THAT TRAFFIC/HIM/THEM/MD80
	2	VICTOR *(airway number);* J *(route number)*
	2	INTERCEPT/JOIN LOCALIZER
	1	RESUME OWN NAVIGATION/PROCEED ON COURSE
		TO JOIN
		***Note*: Omission of "rest of route unchanged" not encoded.**
SPEED		3=MACH *(number--digit point digit), 2=*MACH *(number--point digit)*
		2=*(speed)*
		1=*(number)*
	6	MAINTAIN SPEED (*speed)* TIL *(point)* **OR** MAINTAIN (*speed)* KNOTS TIL *(point)*
	*5-7	REDUCE/INCREASE SPEED TO MACH *(number)*
	5	MAINTAIN (*speed)* KNOTS OR GREATER **OR** MAINTAIN SPEED *(speed)* OR GREATER
	5	AT *(point)* SPEED *(speed)* **OR** AT *(point) (speed)* KNOTS
	5	REDUCE/INCREASE SPEED TO *(speed)* **OR** REDUCE/INCREASE TO *(speed)* KNOTS
	5	SPEED *(speed)* TIL *(point)* **OR** *(speed)* KNOTS TIL *(point)*
	4	MAINTAIN SPEED *(speed)* **OR** MAINTAIN *(speed)* KNOTS
	4	DO NOT EXCEED *(speed)* KNOTS **OR** DO NOT EXCEED SPEED *(speed)*
	3	MAINTAIN *(speed)* **OR** SPEED *(speed)* **OR** *(speed)* KNOTS
	3	DO NOT EXCEED *(speed)* **OR** SLOW TO/GO BACK TO/MAINTAIN *(speed)*
	3	INCREASE/DECREASE *(number)* KNOTS
	2	MAINTAIN PRESENT/THAT/NORMAL SPEED
	2	RESUME NORMAL SPEED
	2	BEST FORWARD SPEED
	1	GO FAST -- NORMAL SPEED
TRANSPONDER	4	RESET TRANSPONDER SQUAWK (*4 digits)*
	3	SQUAWK *(4 digits)*/CODE *(4 digits)*/IDENT
	3	SQUAWK *(4 digits)*/CODE *(4 digits)* **and** IDENT
	2	SQUAWK VFR

APPENDIX B.
Guide to the Computation of Complexity: ATC Advisory Aviation Topics

(*Minimum-Maximum Values)

Note: Plain language – all topics, except where otherwise noted, vary from minimum to maximum values.

AVIATION TOPIC	COMPLEXITY	PHRASEOLOGY
ALTITUDE		4=FLIGHT LEVEL + *(altitude) three digits* 3=*(altitude) two digits* +THOUSAND 2=*(altitude) one digit* + THOUSAND 3=*(altitude) two digits* + HUNDRED 2=*(altitude) one digit* + HUNDRED 2=*(altitude) two digits* 1=*(altitude) one digit*
	7	EXPECT DESCEND/CLIMB & MAINTAIN FLIGHT LEVEL (*altitude*) *two three zero*
	6	EXPECT DESCEND/CLIMB & MAINTAIN *(altitude)* THOUSAND *one zero*
	5	EXPECT DESCEND/CLIMB & MAINTAIN *(altitude)* THOUSAND *four*
	*3-7	*(altitude)* WILL BE YOUR FINAL ALTITUDE
	*3-7	EXPECT DESCEND/CLIMB TO *(altitude)*
	*3-6	EXPECT MAINTAIN *(altitude)*
	*2-3	EXPECT (*altitude*, omitted “THOUSAND” “HUNDRED”)
	*2-4	EXPECT *(altitude)*
	2	HIGHER/LOWER SHORTLY
ALTITUDE RESTRICTION		4=FLIGHT LEVEL + *(altitude) three digits* 3=*(altitude) two digits* + THOUSAND 2=*(altitude) one digit* + THOUSAND 3=*(altitude) two digits* + HUNDRED 2=*(altitude) one digit* + HUNDRED 2=*(altitude) two digits* 1=*(altitude) one digit*
	*5-8	EXPECT CROSS *(point)* AT/ABOVE/BELOW *(altitude)*
	*5-8	EXPECT MAINTAIN *(altitude)* UNTIL *(point)*
	*4-8	EXPECT *(altitude)* TIL ESTABLISHED/LOCALIZER/ESTABLISHED ON LOCALIZER
APPROACH/ DEPARTURE	6	EXPECT ILS RWY *(name)* R/C/L APCH
	6	EXPECT VISUAL APCH RWY *(name)* R/C/L
	5	EXPECT ILS/VISUAL RWY *(name)* R/C/L
	5	EXPECT ILS/VISUAL *(name)* R/C/L APCH
	4	EXPECT ILS RIGHT/LEFT/CENTER APCH
	4	EXPECT DEPART RUNWAY *(number)*
	3	ILS RIGHT/LEFT/CENTER APCH
	3	EXPECT ILS *(name)*
	3	EXPECT RWY *(name)* – PLAN RWY *(name)*
	2	EXPECT APCH/LAND
	2	EXPECT *(type)*
	2	EXPECT VISUAL/ILS
ATIS		NOT INCLUDED IN COMPLEXITY
EQUIPMENT		AIRCRAFT TYPE WOULD BE IN THE TRAFFIC ADVISORY *(Complexity of 2 included in TRAFFIC ADVISORY)*

AVIATION TOPIC	COMPLEXITY	PHRASEOLOGY
GENERAL SIGHTING		NOT INCLUDED IN COMPLEXITY
GENERAL ACKNOW.		NOT INCLUDED IN COMPLEXITY
HEADING	4 4 3 3 3 3 3 2	EXPECT TURN LEFT/RIGHT HEADING *(degrees)* EXPECT TURN *(degrees)* DEGREES LEFT/RIGHT EXPECTTURN LEFT/RIGHT *(degrees)* EXPECT DEPART (*fix*) HEADING (*degrees*) EXPECT HEADING *(degrees)* EXPECT TURN BASE/DOWNWIND (*point)* EXPECT FLY HEADING *(degrees)* EXPECT VECTORS
HOLDING	4 8	EXPECT HOLDING *(fix)* EXPECT HOLDING *(fix)* AS PUBLISHED
NOTAM		NOT INCLUDED IN COMPLEXITY
RADIO FREQUENCY		NOT INCLUDED IN COMPLEXITY
ROUTE/ POSITION	 6 5 *4-6 4-5 3 3 3 3 *2-8 2 2	2=*(miles) two digits* 1=*(miles) one digit* EXPECT INTERCEPT/JOIN RUNWAY *(name)* LEFT/RIGHT LOCALIZER EXPECT FURTHER CLEARANCE VIA J22 EXPECT INTERCEPT/JOIN/RESUME *(airway, course, localizer,* *arrival/departure, etc.)* POSITION *(miles)* MILE(S) IN TRAIL EXPECT DIRECT *(fix)* EXPECT FOLLOW THAT TRAFFIC/HIM/THEM/MD80 EXPECT VICTOR *(airway number)* J *(route number)* EXPECT TAXIWAY *(number/letter)* RADAR CONTACT *(position)*/RADAR SERVICE TERMINATED *(position)* EXPECT INTERCEPT/JOIN LOCALIZER I'LL TURN YOU BACK SHORTLY
SPEED	 *7-8 6 6 6 *5-6 4 4 3-5 3-4 3	3=MACH *(number--digit point digit), 2*=MACH *(number--point digit)* 2=*(speed)* 1=*(number)* EXPECT REDUCE/INCREASE SPEED TO MACH *(number)* EXPECT MAINTAIN (*speed)* KNOTS OR GREATER **OR** MAINTAIN SPEED *(speed)* OR GREATER EXPECT AT *(point)* SPEED *(speed)* **OR** AT *(point) (speed)* KNOTS EXPECT REDUCE/INCREASE SPEED TO *(speed)* **OR** REDUCE/INCREASE TO *(speed)* KNOTS EXPECT (*speed)* KNOTS PRIOR TO *(time/fix/altitude)* EXPECT MAINTAIN SPEED *(speed)* **OR** EXPECT MAINTAIN *(speed)* KNOTS EXPECT HIGHER/SLOWER *(speed)* **OR** EXPECT SLOW TO/GO BACK TO/MAINTAIN *(speed)* EXPECT SPEED REDUCTION/INCREASE *(time/fix/altitude)* EXPECT SPEED REDUCTION/INCREASE SHORTLY *(fix)* EXPECT INCREASE/DECREASE *(number)* KNOTS

AVIATION TOPIC	COMPLEXITY	PHRASEOLOGY
TRAFFIC		1=TRAFFIC 1=O’CLOCK 1=one number for O’Clock, e.g. “TWELVE” 2=two numbers for O’Clock, e.g., “TEN TO TWELVE” 1=MILES 1=one digit for Miles 2=two digits for Miles 1=ALTITUDE 2=ALTITUDE UNKNOWN 4=FLIGHT LEVEL + *(altitude) three digits* 3=*(altitude) two digits* +THOUSAND 2=*(altitude) one digit* + THOUSAND 3=*(altitude) two digits* + HUNDRED 2=*(altitude) one digit* + HUNDRED *2=(altitude) two digits* *1=(altitude) one digit* 1=*(direction)* 1=*(type)*
	*8-14	TRAFFIC *(number)* O’CLOCK *(number)* MILES *(direction)*-BOUND *(altitude)* *(type)*
	*8-14	YOU’RE FOLLOWING *(type)* *(number)* O’CLOCK *(number)* MILES *(altitude)*
	*7-9	TRAFFIC *(number)* MILES *(number)* O’CLOCK ALTITUDE UNKNOWN
	3	YOU’RE FOLLOWING/GOING TO FOLLOW/YOU’LL BE FOLLOWING *(type)*
	2	TRAFFIC (NO FACTOR)
WAKE TURBULENCE	2	CAUTION WAKE TURBULENCE *(Complexity included in ADV TFC except when no ADV TFC issued*
WEATHER (ALTIMETER ONLY)	4 3	ROSWELL ALTIMETER *(4 digits)* ALTIMETER *(4 digits)* ***<u>NOTE</u>: Other weather not included in complexity***

APPENDIX C.

Guide to the Classification of Pilot Readback Errors: Instruction/Clearance Aviation Topics

Variable Descriptions & Value Labels	**Explanation/Examples**
ALTITUDE 1 = Substitution of message numbers/flight level vs. thousand 2 = Substitution of climb with descend or descend with climb 3 = Substitution of message numbers with incorrect climb/descend 4 = Transposition of message numbers with incorrect climb/descend 5 = Transposition of message numbers 6 = Other-one type of information read back as another type of information 7 = Omission of anchor word(s) 8 = Omission of number elements 9 = Omission of both anchor word(s) and some number elements	**ATC – "AAL Ten climb maintain one two thousand"** 1-"maintain one three thousand" "maintain flight level one two" 2-"descend maintain one two thousand" 3-"descend maintain one three thousand" 4-"descend maintain two one thousand" 5-"climb maintain two one thousand" 6-"AAL Ten one two zero knots" 7-"one two" 8-"climb maintain" 9-"climb two thousand"
ALTITUDE RESTRICTION 1 = Substitution of message numbers/rate of descent/climb, substitution of word "expedite" 2 = Substitution of (point/fix) 3 = Substitution of message numbers with incorrect (point/fix) 4 = Transposition of message numbers with incorrect (point/fix) 5 = Transposition of message numbers 6 = Other-one type of information read back as another type of information 7 = Omission of anchor word(s) 8 = Omission of message numbers and/or (point/fix) 9 = Omission of anchor word(s) and some number elements and/or (point/fix)	**ATC – "AAL Ten cross Alpha at or above one two thousand"** 1-"cross Alpha at or above one three thousand" 2-"cross Bravo at or above one two thousand" 3-"cross Bravo at or above one three thousand" 4-"cross Bravo at or above two one thousand" 5-"cross Alpha at or above two one thousand" 6-"descend to one two thousand" Note: "Expedite" clearances – readbacks should include the word "expedite." **ATC – "AALTen expedite climb to one two thousand"** 1-"hurry up to one two thousand" Note: Incorrect rate of climb/descent – "increase rate of climb" for "decrease rate of climb" 7-"cross (point/fix) at one two" "(point/fix) at one two thousand" 8-"cross at or above one two thousand" "cross (point/fix) at or above" 9-"cross VOR at one two"

Variable Descriptions & Value Labels	Explanation/Examples
APPROACH/DEPARTURE	**ATC – “AAL Ten cleared ILS runway two one right approach”**
1 = Substitution of message numbers/(fix)/(route)	1-“cleared ILS runway two two right approach”
2 = Substitution – transposition of message numbers	2-“cleared ILS runway one two right approach”
3 = Substitution of approach name	3-“cleared visual two one right approach”
6 = Other-one type of information read back as another type of information	6-“maintain two one”
7 = Omission of anchor word(s)	7-“cleared two one right”
8 = Omission of number elements, (fix), (route)	8-“cleared to the right”
9 = Omission of anchor word(s) and (fix), (route), some number elements	9-“cleared ILS right”
FREQUENCY	**ATC – “AAL Ten contact (facility) one one eight point three”**
1 = Substitution of message numbers, (facility), (point/fix)	1-“contact (facility) one eight”
2 = Substitution – transposition of message numbers	2-“contact (facility) one eight one point three”
3 = Substitution of message numbers with incorrect (facility), (point/fix)	3- “contact (incorrect facility) one two eight point three”
4 = Transposition of message numbers with incorrect (facility), (point/fix)	4-“contact (incorrect facility) one eight one point three”
5 = Transposition of message numbers	5-“contact (facility) one eight one point three”
6 = Other-one type of information read back as another type of information	6-“squawk one one eight three” **Anchor words “contact,” location, facility, “point/decimal”** **ATC – “AAL Ten contact (facility) one one eight point three”**
7 = Omission of anchor word(s)	7-“contact (facility) one one eight three”
8 = Omission of number elements	8-“contact (facility) one eight point three”
9 = Omission of both anchor word(s) and some number elements	9-“(facility) one eight three”
HEADING	**ATC – “AAL Ten turn left heading two one zero”**
1 = Substitution of message numbers	1-“zero one zero”
2 = Substitution of direction of turn	2-“turn right heading two one zero”
3 = Substitution of message numbers with incorrect direction of turn	3-“right turn one three zero”
4 = Transposition of message numbers with incorrect direction of turn	4-“turn right one two zero”
5 = Transposition of message numbers	5-“turn left one two zero”
6 = Other-one type of information read back as another type of information	6-“AAL Ten two one zero knots”
7 = Omission of anchor word(s)	7-“two one zero”
8 = Omission of number elements	8-“turn left heading” “left on the heading”
9 = Omission of both anchor word(s) and some number elements	9-“two one”

Variable Descriptions & Value Labels	Explanation/Examples
HEADING MODIFICATION 1 = Substitution of rate of turn	**ATC – "AAL Ten increase rate of turn descend maintain four thousand"** 1-"decrease rate of turn"
HOLDING 1 = Substitution of message numbers, (fix/waypoint), (direction), etc. 2 = Substitution – transposition of message numbers 3 = Substitution of message numbers with incorrect (fix/waypoint), (direction), etc. 4 = Transposition of message numbers with incorrect (fix/waypoint), (direction), etc. 5 = Transposition of message numbers 6 = Other-one type of information read back as another type of information 7 = Omission of (fix/waypoint), (direction), (course), (minutes/miles), etc. 8 = Omission of number elements 9 = Omission of (fix/waypoint), (direction), (course), (minutes/miles), etc. and some number elements	**ATC – "AAL Ten hold northeast Alpha one two mile legs right turns"** 1-"hold southwest Alpha" 2-"two one" 3-"southwest Bravo one zero mile legs" 4-"southwest Bravo two one mile legs" 5-"two one" 6-"via Victor twelve" 7-"hold northeast" 8-"hold northeast of Alpha" 9-"hold two mile legs"
ROUTE 1 = Substitution of message numbers, (fix), (route) 2 = Substitution – transposition of message numbers 3 = Substitution of message numbers with incorrect (fix), (route) 4 = Transposition of message numbers with incorrect (fix), (route) 5 = Transposition of message numbers 6 = Other-one type of information read back as another type of information 7 = Omission of (fix)/aircraft/ airport 8 = Omission of part/all of route 9 = Omission of (fix)/aircraft/ airport and part/all of route	**ATC – "AAL Ten via Victor nine J twenty eight Alpha"** 1-"via Victor five J twenty eight Alpha" 2-"via Victor nine J eighty two Alpha" 3-"via Victor eight J twenty eight to Bravo" 4-"via Victor nine J eighty two to Bravo" 5-"via Victor nine J eighty two Alpha" 6-"altimeter's nine twenty eight" 7-"twelve twenty eight" 8-"Victor and the J route (fix)" 9-"Victor and twenty eight" **ATC – "AAL Ten turn right direct (fix)"** 8-"(fix)"

Variable Descriptions & Value Labels	Explanation/Examples
SPEED	**ATC – “AAL Ten reduce speed two one zero knots”**
1 = Substitution of message numbers, (point/fix)	1-“two five zero knots”
2 = Substitution – transposition of message numbers	2-“reduce one two zero knots”
3 = Substitution of message numbers with incorrect increase/decrease	3-“increase speed two five zero knots”
4 = Transposition of message numbers with incorrect increase/decrease	4-“increase one two zero knots”
5 = Transposition of message numbers	5-“reduce one two zero knots”
6 = Other-one type of information read back as another type of information	6-“heading two one zero”
7 = Omission of anchor word(s)	7-“reduce two one zero”
8 = Omission of number elements	8-“reduce speed”
9 = Omission of both anchor word(s) and some number elements	9-“reduce two one”
TRANSPONDER	**ATC – “AAL Ten squawk two one two four”**
1 = Substitution of message numbers	1-“squawk four two one three”
2 = Substitution – transposition of message numbers	2-“squawk one two two four”
6 = Other-one type of information read back as another type of information	6-“altimeter two one two four”
	Anchor word “squawk,” and 4 digits of transponder code
	ATC – “AAL Ten squawk two one two four”
7 = Omission of anchor word(s)	7-“two one two four”
8 = Omission of number elements	8-“squawk”
9 = Omission of both anchor word(s) and some number elements	9-“one two four”

APPENDIX D.

Readback Error Classification Guide: Advisory Aviation Topics

Variable Descriptions & Value Labels	Explanation/Examples
ALTITUDE 1 = Substitution of message numbers 2 = Substitution of climb with descend or descend with climb 3 = Substitution of message numbers with incorrect climb/descend 4 = Transposition of message numbers with incorrect climb/descend 5 = Transposition of message numbers 6 = Other-one type of information read back as another type of information 7 = Omission of anchor word(s) 8 = Omission of number elements 9 = Omission of both anchor word(s) and some number elements	**ATC – "AAL Ten expect climb maintain one two thousand"** 1-"expect maintain one three thousand" 2-"expect descend maintain one two thousand" 3-"expect descend maintain one three thousand" 4-"expect descend maintain two one thousand" 5-"expect climb maintain two one thousand" 6-"AAL Ten expect one two zero knots" **Anchor words "thousand," and/or "hundred" or "flight level" (dependent upon the altitude)** **ATC – "AAL Ten expect climb maintain one two thousand"** 7-"one two thousand" 8-"maintain it" 9-"expecting two"
ALTITUDE RESTRICTION 1 = Substitution of message numbers 2 = Substitution of (*point/fix*) 3 = Substitution of message numbers with incorrect *(point/fix)* 4 = Transposition of message numbers with incorrect *(point/fix)* 5 = Transposition of message numbers 6 = Other-one type of information read back as another type of information 7 = Omission of anchor word(s) 8 = Omission of message numbers and/or *(point/fix)* 9 = Omission of anchor word(s) and some message numbers and/or *(point/fix)*	**ATC – "AAL Ten expect cross Alpha at or above one two thousand"** 1-"expect cross Alpha at or above one three thousand" 2-"expect cross Bravo at or above one two thousand" 3-"expect cross Bravo at or above one three thousand" 4-"expect cross Bravo at or above two one thousand" 5-"expect cross Alpha at or above two one thousand" 6-"expect descend one two thousand" **Anchor words "cross," "til," (*point/fix*), "at" or "at or above/below," "thousand," "hundred," "flight level"** **ATC – "AAL Ten expect cross Alpha at or above one two thousand"** 7-"Alpha at or above one two thousand" 8-"cross Alpha" 9-"two thousand"

Variable Descriptions & Value Labels	Explanation/Examples
APPROACH/DEPARTURE 1 = Substitution of message numbers 2 = Substitution – transposition of message numbers 3 = Substitution of approach name 6 = Other-one type of information read back as another type of information 7 = Omission of anchor word(s) 8 = Omission of number elements 9 = Omission of both anchor word(s) and some number elements	**ATC – "AAL Ten expect ILS runway two one right approach"** 1-"expect ILS runway two two right approach" 2-"expect ILS runway one two right approach" 3-"expect visual approach" 6-"expect maintain two one" **Anchor words approach name/type, the word " runway"** **ATC – "AAL Ten expect ILS runway two one right approach"** 7-"expect two one right" 8-"expect ILS" 9-"expect ILS approach"
HEADING 1 = Substitution of message numbers 2 = Substitution of direction of turn 3 = Substitution of message numbers with incorrect direction of turn 4 = Transposition of message numbers with incorrect direction of turn 5 = Transposition of message numbers 6 = Other-one type of information read back as another type of information 7 = Omission of anchor word(s) 8 = Omission of number elements 9 = Omission of both anchor word(s) and some number elements	**ATC – "AAL Ten expect turn left heading two one zero"** 1-"zero one zero," or "six zero" 2-"turn right two one zero" 3-"right two two zero" 4-"expect turn right heading one two zero" 5-"expect turn left heading one two zero" 6-"expect two one zero knots" **Anchor words "heading" or "degrees** **ATC – "AAL Ten expect turn left heading two one zero"** 7-"left two one zero" 8-"expect left heading two one" 9-"expect left two one"
HOLDING 1 = Substitution of message numbers, (*facility,)* (*point/fix)* 2 = Substitution – transposition of message numbers 3 = Substitution of message numbers with incorrect *(facility), (point/fix)* 4 = Transposition of message numbers with incorrect *(facility), (point/fix)* 5 = Transposition of message numbers 6 = Other-one type of information read back as another type of information 7 = Omission of any item(s)	**ATC – "AAL Ten expect hold south of *(fix) (radial, airway, etc.) (direction)* turns *(minutes/hours)* delay"** 1-Substitution of any of the elements in holding advisory 2-Transposition of any number elements in holding advisory 3-Substitution of message numbers with incorrect holding fix 4-Transposition of message numbers with incorrect holding fix 5-Transposition of any of the number elements 6-"cleared for approach" 7-Omission of any item(s) in holding advisory

Variable Descriptions & Value Labels	Explanation/Examples
ROUTE	**ATC – "AAL Ten expect Victor nine J twenty eight Alpha"**
1 = Substitution of message numbers	1-"expect Victor five J twenty eight Alpha"
2 = Substitution – transposition of message numbers	2-"expect Victor nine J eighty two Alpha"
3 = Substitution of message numbers with incorrect *(point/fix)*	3-"expect Victor five J twenty eight Bravo"
4 = Transposition of message numbers with incorrect *(point/fix)*	4-"expect Victor nine J eighty two Bravo"
5 = Transposition of message numbers	5-"expect Victor nine J eighty two Alpha"
6 = Other-one type of information read back as another type of information	6-"speed two eighty"
	Anchor words/phrases "expect," "direct," "intercept/join," "radial," "maintain visual/visual separation from/with traffic/him/type/ACID," "follow that traffic/him/type/ACID."
7 = Omission of anchor word(s), *(fix)*, route	Use of "direct," must include a (*point/fix*)
8 = Omission of number elements	Use of "intercept/join" must include localizer name.
9 = Omission of anchor word(s), *(fix)*, route, and some number elements	Use of "radial" must include identification of the radial.
SPEED	**ATC – "AAL Ten expect reduce speed two one zero knots"**
1 = Substitution of message numbers	1-"expect two five zero knots"
2 = Substitution – transposition of message numbers	2-"expect reduce zero one two knots"
3 = Substitution of message numbers with incorrect increase/decrease	3-"expect increase speed two five zero knots"
4 = Transposition of message numbers with incorrect increase/decrease	4-"expect increase zero one two knots"
5 = Transposition of message numbers	5-"expect reduce zero one two knots"
6 = Other-one type of information read back as another type of information	6-"expect heading two one zero"
	Anchor words "speed" or "knots," "mach" (including point)
	ATC – "AAL Ten expect reduce one eight zero knots"
7 = Omission of anchor word(s)	7-"expect one eight zero"
8 = Omission of number elements	8-"expect reduce"
9 = Omission of both anchor word(s) and some number elements	9-"expect eight oh"
WEATHER (ALTIMETER)	**ATC – "AAL Ten *(source)* altimeter two nine nine two"**
1 = Substitution of message numbers	1-"altimeter nine two nine zero"
2 = Substitution – transposition of message numbers	2-"altimeter nine two nine two"
5 = Transposition of message numbers	5-"altimeter nine two two nine"
6 = Other-one type of information read back as another type of information	6-"squawk two nine nine two"
	Key word "altimeter" and four digits
7 = Omission of anchor word	7-"(source) two nine nine two"
8 = Omission of number elements	8-"(source) altimeter nine two"
9 = Omission of both anchor word(s) and some number elements	9-"(source) nine nine two"